Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

Mining Research Laboratories
Laboratoires de recherche minière

Canada/NB MDA Project on Mine-shaft Rope Testing; testing of 1.000 in., 6×27, F. S., H. R., (our rope #2)

L.B. Geller, D. Poffenroth, J.E. Udd, and D. Hutchinson

MRL 91-001 (TR)

January, 1991

Canada

91-05144/

Canada/NB MDA Project on Mine-shaft Rope Testing; testing of 1.000 in., 6×27, F. S., H. R., (our rope #2)

L.B. Geller, D. Poffenroth, J.E. Udd, and D. Hutchinson

MRL 91-001 (TR) January, 1991

39 pp

MICROMEDIA

CANADA/NB MDA PROJECT ON MINE-SHAFT ROPE TESTING; TESTING OF 1.000 in., 6×27, F. S., H. R. (OUR ROPE #2)

by

L.B. Geller*, D. Poffenroth†, J.E. Udd**, and D. Hutchinson††

ABSTRACT

In this report the authors analyse the test-results obtained both non-destructively, and destructively, on a 1.000 in. diameter, 6×27, flattened-strand (F. S.), hoist-rope (H.R.). The rope was examined both in-situ and on the shop-floor as part of CANMET's project to comparatively evaluate the performance of a range of EM wire-rope testers. This is the first time that a project of this magnitude and diversity has been undertaken.

The rope, when tested in-situ with a Rotesco AC instrument, was reported to contain a maximum strength loss (LBS_{max}) of 5.5%. On the shop-floor the rope was tested, reel-to-reel, with the Canadian Magnograph, Rotesco AC, and Rotescograph, the American LMA-250, and the German WBK instruments. Maximum estimated LBS was reported at 5.2% by the Rotescograph operator, at 6.7% by the Rotesco AC operator, and at 9.0% by the Magnograph operator. The operators of the American and German instruments did not submit LBS estimates.

The results obtained are analysed with special reference to such important parameters as their repeatability, comparability, and levels of accuracy.

---

* Research Scientist, and ** Director, Mining Research Laboratories, CANMET, Energy Mines and Resources Canada, Ottawa; and † Electronics Engineer, and ††Chief, Industrial and Electrical Safety Division, MSHA, United States Dept. of Labor, Denver.

Keywords: New Brunswick; Mineral Development Agreement; Wire-ropes; Non-destructive-testing; Electro-magnetic instruments; Hoist-ropes; Stranded ropes

PROJET D'EEM CANADA/NB SUR DES ESSAIS DE CÂBLES DE PUITS DE MINE; ESSAI D'UN CÂBLE DE LEVAGE DE 1 PO À 6X27 TORONS PLATS (NOTRE CÂBLE NO 2)

par

L.B. Geller[1], D. Poffenroth[2], J.E. Udd[3] et D. Hutchinson[4]

RÉSUMÉ

Dans le présent rapport, les auteurs analysent les résultats d'essais tant destructifs que non destructifs sur un câble de lavage (CL) de 1 po de diamètre à 6x27 torons plats (TP). Le câble a été examiné sur place et à l'atelier dans le cadre du projet de CANMET visant à évaluer le rendement d'une gamme d'appareils ÉM d'essai des câbles métalliques. C'est la première fois qu'un projet de cette envergure et de cette diversité est entrepris.

Le câble, lorsqu'essayé sur place au moyen d'un appareil Rotesco AC, a présenté une perte de résistance maximum (PRR_{max}) de 5,5 %. À l'atelier, le câble a été vérifié sur toute sa longueur au moyen des instruments canadiens Magnograph, Rotesco AC et Rotescograph, américain LMA-250 et allemand WBK. La PRR maximum a été estimée à 5,2 % par l'opérateur du Rotescograph, à 6,7 % par l'opérateur du Rotesco AC et à 9,0 % par l'opérateur du Magnograph. Les opérateurs des instruments américain et allemand n'ont pas fourni d'estimations de la PRR.

Les résultats obtenus sont analysés, notamment eu égard à des paramètres aussi importants que leur répétabilité, leur comparabilité et leurs niveaux de précision.

---

[1]Chercheur scientifique et [2]Directeur, Laboratoires de recherche minière, CANMET, Énergie, Mines et Ressources Canada, Ottawa; et [3]ingénieur-électronicien et [4]Chef, Division de la sécurité industrielle et électrique, MSHA, ministère américain du Travail, Denver.

Mots clés: Nouveau-Brunswick; entente sur l'exploitation minérale; câbles métalliques; essai non destructif; instruments électromagnétiques; câbles de levage

CONTENTS

	Page
ABSTRACT	i
RÉSUMÉ	ii
BACKGROUND	1
ROPE DETAILS	1
IN-SITU TEST RESULTS — AS REPORTED AND REVIEWED	1
SHOP-FLOOR TEST RESULTS — AS REPORTED AND REVIEWED	2
DESTRUCTIVE TESTING	5
ANALYSIS OF TEST RESULTS	6
REFERENCES	8
APPENDIX 1: Tables 1, 2 and 3, as well as Figures 1 to 8	10

BACKGROUND

The results described in this report constitute an integral part of the contracted phase of CANMET's project, undertaken in 1986 in response to requests by both the mining industry and the mine regulatory authorities. The basic project objectives specified that the continuing rope failures, or near failures — occurring despite mandatory wire-rope examinations with electro-magnetic (EM) instruments at regular intervals — be examined, documented, analysed, and the reasons for these occurrences clarified. This is the first time a project of this scope and depth has been undertaken, anywhere.

CANMET's work included both in-house and contracted work phases. The in-house phase resulted in a range of conclusions and recommendations, reported elsewhere (references 1 through 4). We are now in the process of reporting the results obtained during the contracted project-phase, which included an extensive series of both in-situ and shop-floor tests. The first twelve reports to describe this project phase were prepared in the period February, 1990, through January, 1991 (references 5 through 16). More are to follow.

ROPE DETAILS

The rope which is the subject of this report (referred to as "our rope #2") was used as a hoist-rope in Compartment #2 (left), Shaft #2 (Henderson), by Les Mines Camchib Inc., at Chibougamau, Québec. It was a 1.000 in. diameter, 6×27, F.S., rope, reel #L-13692. It was installed on 1980 05 12*, and discarded on 1988 09 10. We do not, unfortunately, have any further details about this rope's operational history, other than the relevant Rotesco AC results. These are listed hereunder.

IN-SITU TEST RESULTS — AS REPORTED AND REVIEWED

The Rotesco AC data

The in-situ tests were undertaken, under standard operating conditions, by a service company. The maximum LBS (i.e., LBS_{max}) estimates were: negligible on 1980 09 30; on 1981 05 13; on 1981 09 21; on 1982 03 29; on 1982 09 20; on 1983 03 16; and on

*: dates are given in this order: year, month, day

1983 09 28. Subsequently, 2.0% was reported on 1984 03 26; on 1985 03 25; on 1985 10 08; and on 1986 03 24 along some 15-50 ft of rope length at about 220-250 ft from start of the test above the cage. Later, 3.0% was reported on 1986 10 19, and on 1987 04 13, in the same general area above the cage. Finally, on 1988 04 21 the reported LBS_{max} was 5.5% between 255-265 ft, and 270-280 ft from start of the test above the cage. Moreover, during a visual inspection of the latter rope segments evidence was found of corrosion in the form of slight pitting on the outer wires, in addition to flattening on the crown-wires.

A copy of the operator's latest (test #SQ-33) in-situ strip-chart is reproduced in Fig. 1a. We added to it our own marking of the 100% reference level, and the 2.8% LMA chart-reading at the rope defect location 'X'. In Fig. 1b we juxtapose to the foregoing in-situ chart a copy of the 1989 04 03 shop-floor Rotesco AC strip-chart, again with the 0.0% LMA reference level and the LMA chart-reading (3.6%) at the characteristic rope-defect location 'X', added. Tested rope-length was 1,700 ft in-situ, and 2,330 ft on the shop-floor. The relevant data are tabulated in Table 1.

We agree with both the reported in-situ and shop-floor results.

SHOP FLOOR TEST RESULTS — AS REPORTED AND REVIEWED

General procedure

The shop-floor tests were undertaken with three Canadian (the Rotesco AC, Rotescograph and Magnograph), one American (the LMA-250), and a West German tester (the prototype version of the latest German WBK instrument). The operators were known to, and approved by, the instrument makers/designers. None of them knew about each other's results before these were submitted to us. All details of the shop-floor testing process have been described, and illustrated, elsewhere (5).

The Rotesco AC data

Shop-floor testing with the Rotesco AC instrument was undertaken, on its own, on 1989 04 03, before any of the other shop-floor tests with the permanent magnet instruments were performed. The operator reported an LMA_{max} of 3.8% at 2,050 ft from the start of the test at the drum rope-end. The test-chart is reproduced in Fig. 1b, in juxtaposition with its in-situ counterpart (Fig. 1a). The comparability of these two charts, obtained under different test conditions, at different times, and by different

operators, is remarkable. These results (Table 1) confirm the legitimacy of comparing in-situ and reel-to-reel test results, as had been stated before elsewhere (11).

The operator marked the location of the seizing-wire markers. The operator also submitted an LBS estimate of 6.7% for the 2,050 ft rope segment, i.e., for the characteristic rope defect section 'X' (Fig. 1b).

We agree with the reported data.

The Magnograph data

Shop-floor testing with the Magnograph was undertaken on 1989 04 04. The operator reported an LMA_{max} of 4.0% (report #89-286I) at the 2,076 ft rope segment (i.e., at rope defect 'X') from start of the test at the drum rope-end. The test-chart is reproduced in Fig. 2, complete with our own marking of the 0.0% LMA level and the characteristic rope-defect 'X'. The rope length tested was 2,367 ft. The operator only marked the 4.0% LMA_{max} reading on his chart. While no other LMA readings were marked, the location of nine local faults, and of the seizing-wire markers, were noted.

The operator also submitted an LBS estimate of 9.0% for the 2,080 ft rope segment, i.e., for the one containing rope defect 'X'.

We agree with the operator's report.

The LMA-250 data

Shop-floor testing with the LMA-250 instrument was performed on 1989 04 04. The rope length tested was 2,148 ft. Testing commenced at the drum rope-end. The 0.0% LMA was at the drum rope-end. The LMA difference between the two rope-ends was 0.6%.

The operator submitted a report, and marked the chart with: (a) the 0.0% LMA level, (b) the location of the seizing-wire rope-markers M_1 to M_{10}, (c) a number of LMA chart readings, and (d) some of the broken wires detected. We reproduce this chart in Fig. 3, complete with our own marking of characteristic rope-defect location 'X'. The operator's report also contains comments on apparent corrosion between markers M_9 and M_{10}.

We agree with the operator's report.

The Rotescograph data

Shop-floor testing with the Rotescograph was first performed on 1989 04 04 with test-start at the drum rope-end (Fig. 4a), and a second time on 1989 04 10 with test-start at the cage rope-end (Fig 4b). According to the strip-charts the rope length tested was 2,365 ft and 2,440 ft, respectively. On both occasions the 0.0% LMA level was both at the drum and at the cage rope-ends. On both occasions the operator marked the seizing-wire locations — which showed up well on both the LMA and LF chart-traces — and the rope-advance footages. However, an LMA_{max} reading was only marked on the 1989 04 10 chart (Fig. 4b). It was shown to be 2.6% at some 280 ft from the cage rope-end (i.e., at defect 'X'). We added our own 100% reference level and rope defect location markings to the operator's charts.

We agree with the operator's chart-readings.

The operator also submitted an LBS_{max} estimate of 5.2%. It was calculated by doubling the respective LMA chart-reading at the corresponding rope-location. The operator's report also referred to minor corrosion throughout the entire rope length.

The WBK data

Shop-floor testing was performed on 1989 04 10 with the German WBK instrument — side-by-side with the Rotescograph test-run. The rope length tested was 2,365 ft (719 m). The strip-chart contains, reading from top-to-bottom: five LF traces, a %LMA trace, and a length indication scale (in meters). There is also space for a second %LMA trace and for a rope-diameter indication-trace (not used in the current test-series). With the sensor-head closed, the individual measuring coils LF #1 and LF#2 were joined together, and so were #3 and #4. The fifth LF chart-trace summarizes the output of these two individual traces. Surface defects, such as the seizing-wire markers, were particularly conspicuous on this instrument's LF and LMA traces.

The two WBK operators carefully annotated their charts, including some LMA readings and the seizing-wire marker (M1 to M10) locations. They also submitted a report. Testing commenced at the cage rope-end. There was no LMA difference between the two rope-ends.

We did not receive a copy of the complete strip-chart. Instead copies of the important chart sections were submitted, numbered Figures 2.1 to 2.13, inclusive. We reproduce these as our Fig. 5. As may be seen, the 0.0% LMA reference level was set along the cage rope-end; the %LMA scale was 0.61% per mm of full-scale diagram (see

'Fig. 2.1' of our Fig. 5). We added our own marking of the 'X' rope defect location, and of the height of the %LMA chart-spikes at the seizing-wire markers. Test results are tabulated in Table 1.

The German report included a tabulation of the M1 to M10 marker locations. It is interesting to note that the tabulated distance between these markers was consistently 75.5 m (247.7 ft). The corresponding 'true' distance was 250 ft. We agree with the operators' report.

DESTRUCTIVE TESTING

Two 16-ft samples were cut from our rope #2 for destructive testing. From these, contiguous samples, each 8-ft long, were used for destructive testing, and for external and internal visual inspection.

The general test procedure has been described and illustrated elsewhere (6).

The samples for destructive testing were designated as samples #2a, and #2b. With reference to Fig. 2:

Sample #2a: was cut from the cage rope-end, at the 'Mk 2,250 pi' marker end, i.e., from the rope section containing an LMA chart-reading of 0.0% (Fig. 2);

Sample #2b: was cut from the 2,076 ft rope segment, i.e., from the rope section containing the 'X' defect with an LMA chart-reading of 4.0% (Fig. 2).

Destructive testing was performed in the laboratories of Wire Rope Industries (WRI) Ltd., at Pointe Claire, Quebec. Standard procedures were followed, as monitored by Messrs. G. Rousseau (of CANMET) and R. Boles (of WRI).

As mentioned before, operational records of this rope, including information about its original breaking strength, were not available. We knew, however, that similar hoist-ropes broke at 84,250 lb to 125,000 lb, when new (1). Also, manufacturer's catalogues (e.g., see Fig. 5 of ref. 15) list the breaking strength of similar ropes in the range of 99,000 to 125,000 lb. *Faute de mieux*, we decided to designate the 112,000 lb breaking strength of our own sample #2a as the "original" rope breaking-strength.

Our destructive test results were as follows:

Sample #2a: 112,000 lb, i.e., a loss of 0.0% of the assumed "original" 112,000 lb strength, at a point where the maximum LMA chart reading is 0.0% (Fig. 2). Sample diameter was 1.020 in.;

Sample #2b: 112,000 lb, i.e., a loss of 0.0% of the assumed "original" 112,000 lb strength, at a point where the maximum LMA chart reading is 4.0% (Fig. 2). Sample diameter was 1.022 in.

The test conditions are illustrated in Fig. 6. Conditions of the broken samples are illustrated in Figures 7 and 8. These were as follows:

Sample #2a: four strands, as well as additional wires in the other two strands, broke approximately one ft from the cone. Light lubrication was visible. The broken wires exhibited mostly shear breaks;

Sample #2b: five strands broke approximately 6 in. from the cone. There was light surface wear and light rusting. The broken wires exhibited mostly shear breaks.

ANALYSIS OF TEST RESULTS

(1) General comments

We tabulated both the in-situ and shop-floor chart-readings in Table 1. Details of the test set-ups are listed in Table 2. Considering the influence of the instrument calibration-procedures upon the test-results, we included relevant information about these matters in Table 1, such as: (a) the rope-end at which calibration was effected, (b) the rope-end at which 0.0%LMA was found to be, and (c) the %LMA difference between the two rope-ends.

The rope-markers M1–M10 are very helpful in providing accurately located "fingerprints" for comparing the respective %LMA chart readings of the various EM instruments. Moreover, the height of the LMA 'spikes' produced by them provide a useful basis for comparing the quantitative resolution of the EM testers. We, therefore, included the foregoing information in Table 1.

Wherever we were unable to reproduce the strip-charts in a single length, we provided match-marks (such as: ref. 'A'; ref. 'B'; etc.) on the individual chart-segments. Moreover, we added to all charts: (a) the 100% reference levels, (b) the relevant sensitivity scales (%LMA per major chart-division), (c) the 'X' rope defect location and (d) the %LMA chart-readings at the most important rope-locations.

(2) LF chart-readings:

Broken wires showed up quite consistently on the LF-traces of all the instruments. The WBK traces were particularly explicit in case of surface flaws. For easy comparison we listed the major LF chart locations in Table 3.

(3) LMA chart readings

The in-situ and shop-floor chart-traces were easy to positively position, and compare, at the characteristic rope defect location 'X'. Moreover, a comparative evaluation of the five EM instrument types used can, perhaps, be best based on the LMA chart-readings (Table 1) obtained at the ten seizing-wire rope-marker locations M1 to M10. These markers consisted of $\frac{1}{16}$ in. diameter wire, wound around the 1.000 in. rope at 250 ft intervals along 2 in. stretches. Noting that the metallic cross-sectional area (A) of the rope itself was assumed to be 0.4578 in^2, addition of the seizing-wire represented a metallic area increase of some 35%. It will be noted that in Table 1 we listed both the %LMA chart-readings, and the height of the LF trace perturbations (i.e., 'spikes'), at these markers. The 'spikes' on the WBK chart-traces are particularly conspicuous.

In this context, though, we must also emphasize the different quantitative resolutions of the five instruments, exemplified, as an example for the Magnograph, by Fig. 32c in reference 5.

On the basis of operator and instrument related observations made in previous reports of this series (see references 1 through 16), we think that the %LMA chart-readings in Table 1 are, on the whole, in fair agreement. The rope was in a relatively good condition, with none of the %LMA chart-readings exceeding 4.9%.

(4) LBS estimates

Since we had no reliable information about the rope's original breaking-strength, we had no way of checking the accuracy of the operators' LBS estimates. It is interesting to note, though, that these ranged from a low of 5.0% to a high of 9.0%.

(5) Comparability: in-situ vs shop-floor test results

The in-situ and shop-floor LMA chart-readings in Table 1 are in fair agreement. This supports the previously stipulated contention (11) that in-situ and reel-to-reel EM tests can be legitimately compared.

REFERENCES

1. Geller, L.B.; Udd, J.E.; and Mitchell, E.W. "Comparative evaluation of mine-shaft wire-rope NDT instruments: a search for, and analysis of, background information — contribution to the Canada/USBM/Ontario MOL joint R&D program"; CANMET Division Report MRL 88-78, 139 pp; July, 1988.

2. Geller, L.B.; Anderson, G.L.; Miscoe, A.J.; and Mitchell, E.W. "The safety of mine-shaft wire-ropes — cooperative work by Canada and the U.S.A."; CANMET Division Report MRL 89-14, 28 pp; February, 1989.

3. Geller, L.B.; Udd, J.E.; Blanchard, R.; and Daniel, K.E. "About electro-magnetic wire-rope testing in New Brunswick mines, and related data"; CANMET Division Report MRL 89-40, 51 pp; October, 1989.

4. Geller, L.B.; and Rousseau, G. "Effect of trapped wire-rope debris upon an EM instrument's LMA chart-trace"; CANMET Division Report MRL 90-08, 29 pp; February, 1990.

5. Geller, L.B.; Rousseau, G.; and Poffenroth, D. "Canada/NB MDA project on mine-shaft rope testing; stranded ropes with artificial defects"; CANMET Division Report MRL 90-015, 117 pp; February, 1990.

6. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 1/4 in., FLC, H.R. (our rope #4)"; CANMET Division Report MRL 90-044, 76 pp; May, 1990.

7. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Evaluation of EM rope testers: Canada/US joint work"; CANMET Division Report MRL 90-052, 24 pp; June, 1990.

8. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 7/16 in., FLC, H.R. (our rope #5)"; CANMET Division Report MRL 90-053, 46 pp; June, 1990.

9. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 7/8 in., 34×7, NR, T.R., (our rope #9)"; CANMET Division Report MRL 90-060, 48 pp; July, 1990.

10. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 7/8 in., 34×7, NR, T.R., (our rope #12)"; CANMET Division Report MRL 90-069, 30 pp; July, 1990.

11. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 1/2 in., 60×30, H.R. (our rope #7)"; CANMET Division Report MRL 90-071, 128 pp; August, 1990.

12. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1.000 in., H.R., (our rope #1)"; CANMET Division Report MRL 90-131, 43 pp; December, 1990.

13. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1.000 in., 6×27, FS, H.R., (our rope #2)"; CANMET Division Report MRL 91-001, 30 pp; January, 1991.

14. Geller, L.B.; Poffenroth, D.; Udd, J.E.; and Hutchinson, D. "Canada/NB MDA project on mine-shaft rope testing; testing of 1 3/4 in., 6×25, RS, H.R., (our rope #10)"; CANMET Division Report MRL 91-002, 30 pp; January, 1991.

15. Geller, L.B.; and Kitzinger, F. "Techniques to better exploit the possibilities of wire-rope testing with electro-magnetic instruments"; CANMET Division Report MRL 91-003, 70 pp; January, 1991.

16. Geller, L.B.; and Udd, J.E. "How accurate are non-destructive-testing based estimates of mine shaft rope breaking-strength losses? — an update"; CIM Bull., 83, no. 944, pp. 47-50; December, 1990.

APPENDIX 1

Tables 1, 2, and 3

as well as Figures 1 to 8, inclusive

Table 1

In situ and shop-floor test-results

	In-situ	Shop-floor					
	Rot. AC	Rot. AC	Magnogr.	LMA-250	Rotescogr.	Rotescogr.	WBK
	1988 04 21	1989 04 03	1989 04 04	1989 04 04	1989 04 04	1989 04 10	1989 04 10
Subject	Fig. 1a	Fig. 1b	Fig. 2	Fig. 3	Fig. 4a	Fig. 4b	Fig. 5
tested rope length	1,700 ft	2,330	2,367 ft	2,148 ft	2,365 ft	2,440 ft	2,365 ft
%LMA:							
@ 'X'	2.8%	3.6%	4.0%	4.9%	2.5%	2.6%	4.9%
@ ft*	255 ft	280	289 ft	283 ft	285 ft	280 ft	295 ft
calib. @:							
cage;	yes	—	—	—	—	yes	yes
drum;	—	yes	yes	yes	yes	—	—
0.0% LMA @:	drum	from M3-M7	both ends	drum & @ M6	both ends	both ends	both ends
%LMA diff. betw. ends:	0.8%	0.2%	0.0%	0.6%	0.0%	0.0%	0.0%
%LMA chart-read & (spike-height) @:							
$M_1^{\dagger}$	—	0.5%;(0.2%)	0.0%;(0.5%)•	0.0%;(‡)	0.1%;(0.7%)	0.0%;(0.8%)	0.0%;(7.3%)
M_2	—	0.4%;(0.4%)	0.8%;(0.5%)	0.4%	0.5%;(0.8%)	0.3%;(0.8%)	0.0%;(6.7%)
M_3	—	0.2%;(0.1%)	1.0%;(0.5%)	0.8%	0.5%;(0.6%)	—	—
M_4	—	0.0%;(0.2%)	0.0%;(0.5%)	0.5%	0.3%;(0.7%)	0.3%;(0.6%)	—
M_5	—	0.2%;(0.3%)	0.0%;(0.5%)	0.5%	0.2%;(0.8%)	0.2%;(1.0%)	—
M_6	—	0.0%;(0.4%)	0.0%;(0.5%)	0.5%	0.3%;(0.8%)	0.2%;(0.9%)	—
M_7	—	0.1%;(0.2%)	0.0%;(0.5%)	0.6%	0.1%;(0.8%)	0.1%;(0.7%)	—
M_8	—	0.3%;(0.8%)	0.0%;(0.5%)	0.6%	0.2%;(0.8%)	0.2%;(0.8%)	—
M_9	—	0.4%;(0.6%)	0.0%;(0.5%)	0.4%	0.0%;(1.0%)	0.2%; (—)	0.0%;(7.3%)
M_{10}	—	0.9%;(0.8%)	0.0%;(0.5%)	0.0%	0.0%;(1.2%)	0.0%;(1.2%)	0.0%;(8.5%)

*: from the cage rope-end

†: closest to the cage rope-end

•: all 0.5% Magnograph readings too small for accuracy; but clear LF perturbations

‡: tips of all spikes off the LMA strip-chart

Table 2

Details of EM testing of the 1.000 in., 6×27, H.R.

Item No.	Test Instr.	Test No.	Test date	Test location	Instr. operator*	Test chart: Fig. #
1	Rotesco AC	#SQ-33	1988 04 21	in-situ	(1)	1a
2	Rotesco AC	—	1989 04 03	shop-floor	(4)	1b
3	Magnograph	#89-2861	1989 04 04	shop-floor	(2)	2
4	LMA-250	—	1989 04 04	shop-floor	(5)	3
5	Rotescograph	—	1989 04 04	shop-floor	(6)	4a
6	Rotescograph	ME-0004RPN	1989 04 10	shop-floor	(6)	4b
7	WDK	—	1989 04 10	shop-floor	(7)	5

* (1) and (7): instr. designer/maker and service company
(2) service company
(4) and (6): mining company
(5) government organization

TABLE 3

Major LF locations on shop-floor charts and/or reported

Distance from drum rope end (ft)				
Magnograph Fig. 2	LMA-250 Fig. 3	Rotescograph		WDK Fig. 5
		Fig. 4a	Fig. 4b	
9; 30; 35;	148	185; 212; 237;	170	6; 9; 19
186; 222;	200	350; 380; 421;	208	
248;		442; 720; 733;	230	
		735; 764;		1,870
	800	1,370;		
	1,225			2,004 to
				2,122
2,178		1,714; 1,722		2,129
2,180		1,761; 1,939		2,155
2,198		2,173; 2,317		
2,244			2,255	

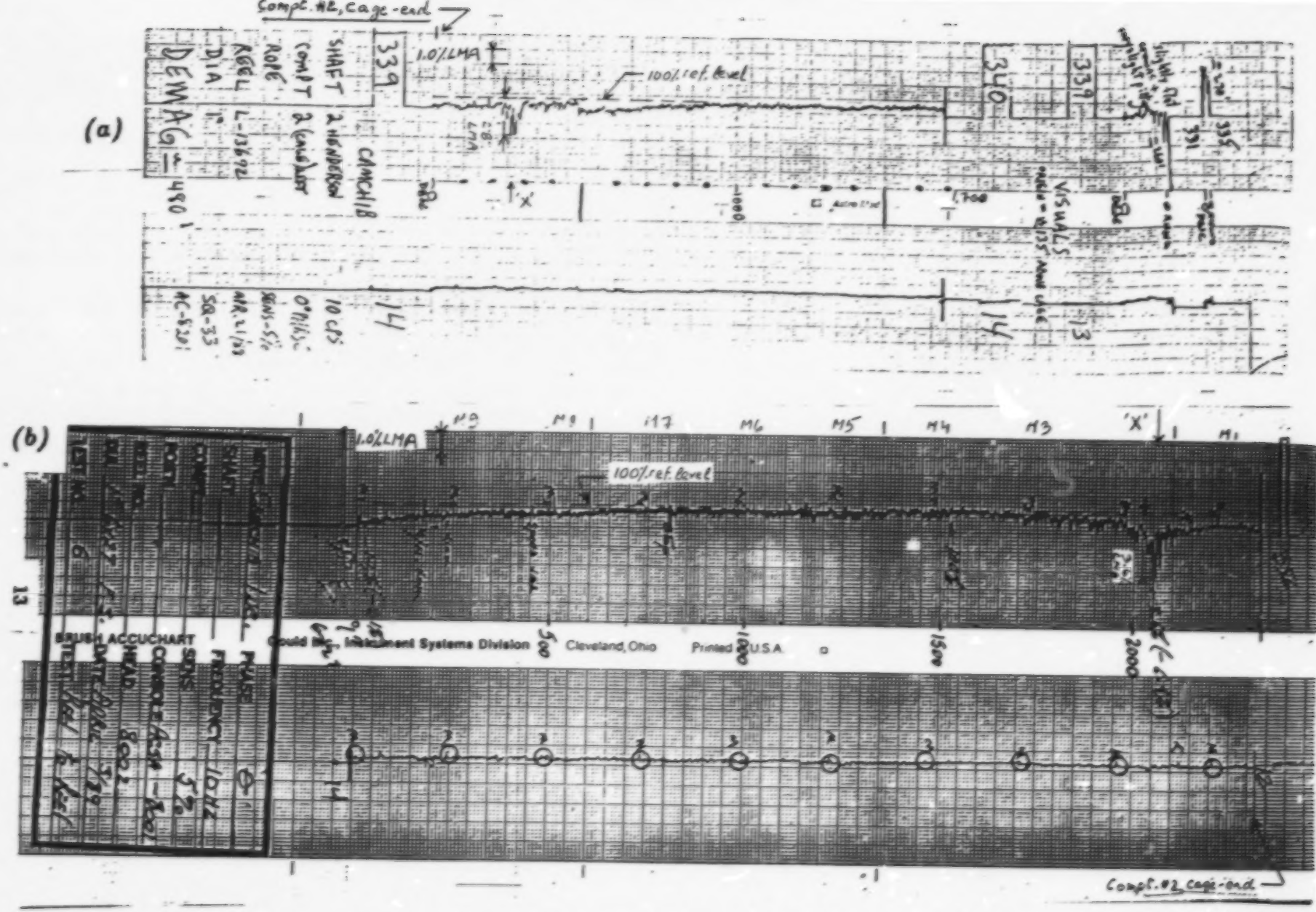


Fig. 1 — Rotesco AC test: (a) in-situ of 1988 04 21, and (b) shop-floor of 1989 04 03

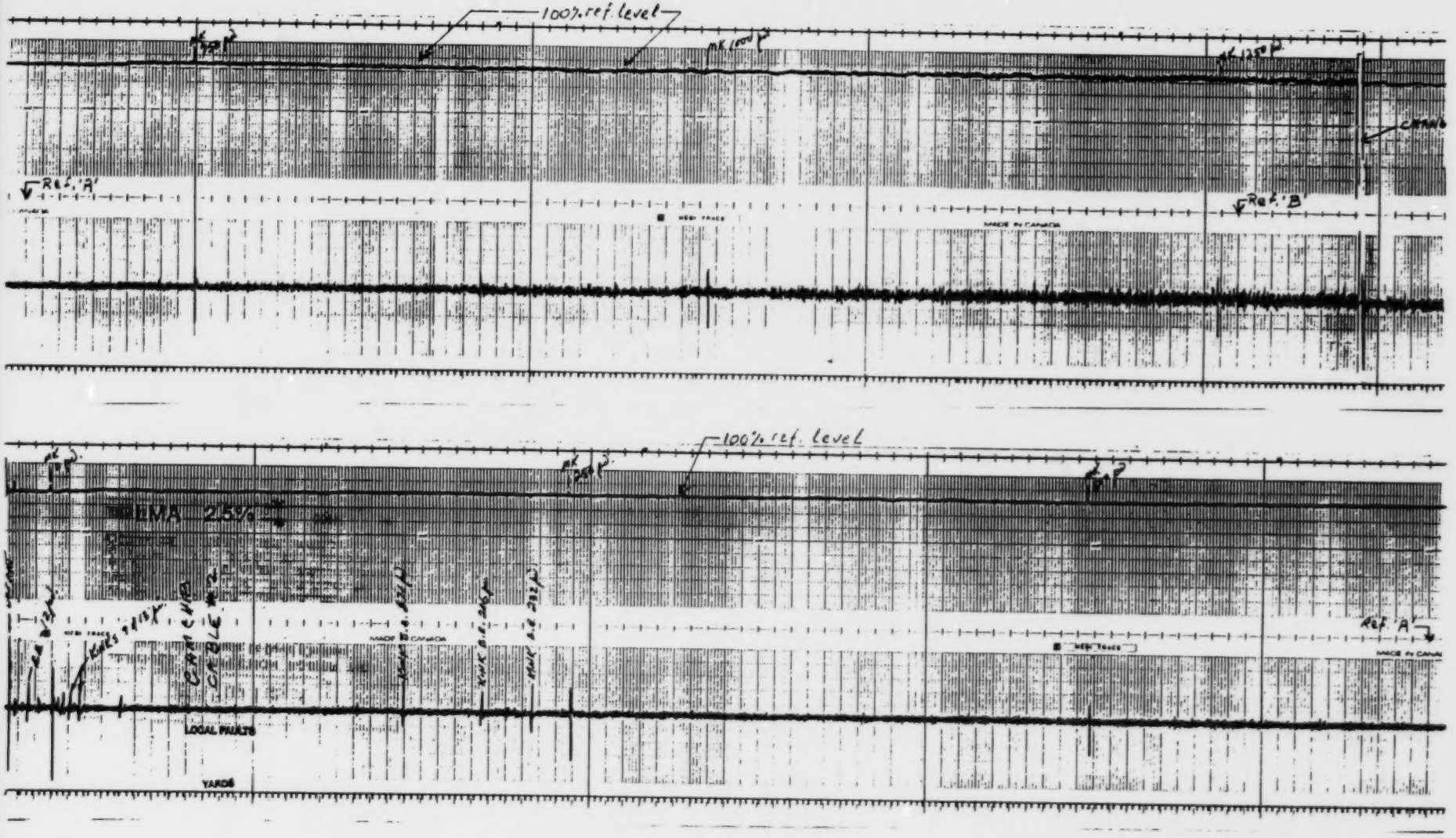


Fig. 2 — Magnograph shop-floor test of 1989 04 04

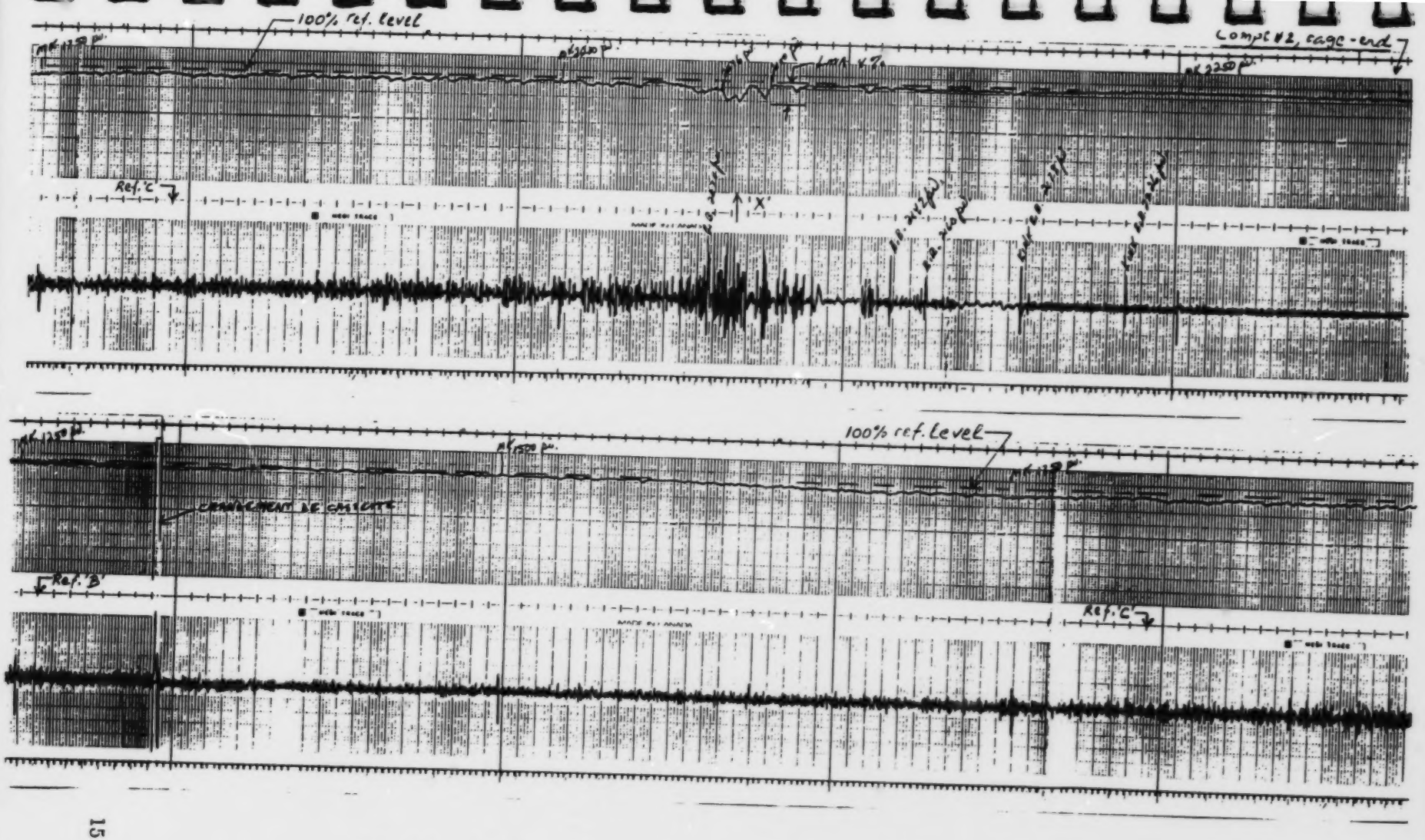


Fig. 2 (continued)— Magnograph shop-floor test of 1989 04 04

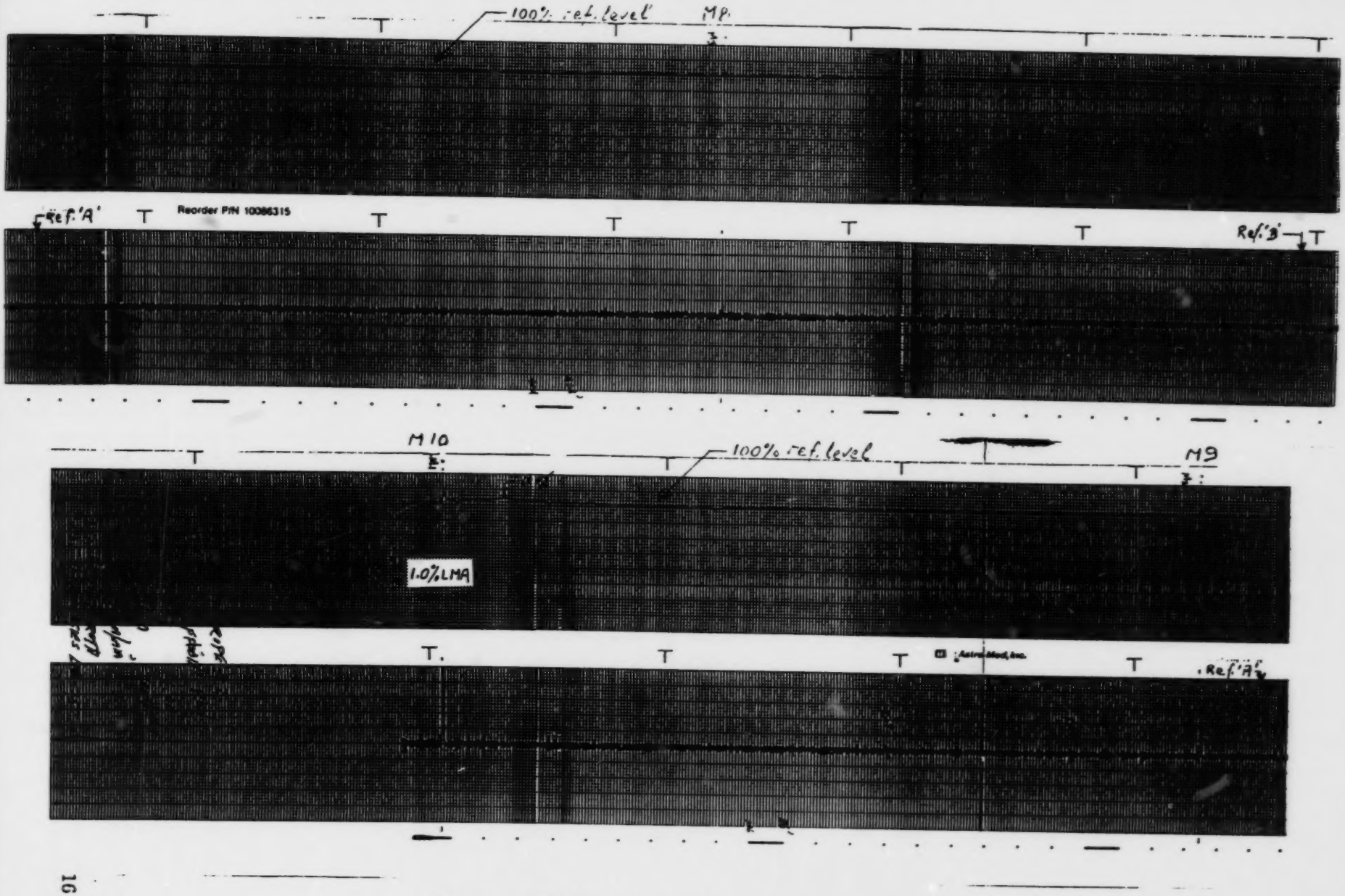


Fig. 3 — LMA-250 shop-floor test of 1989 04 04

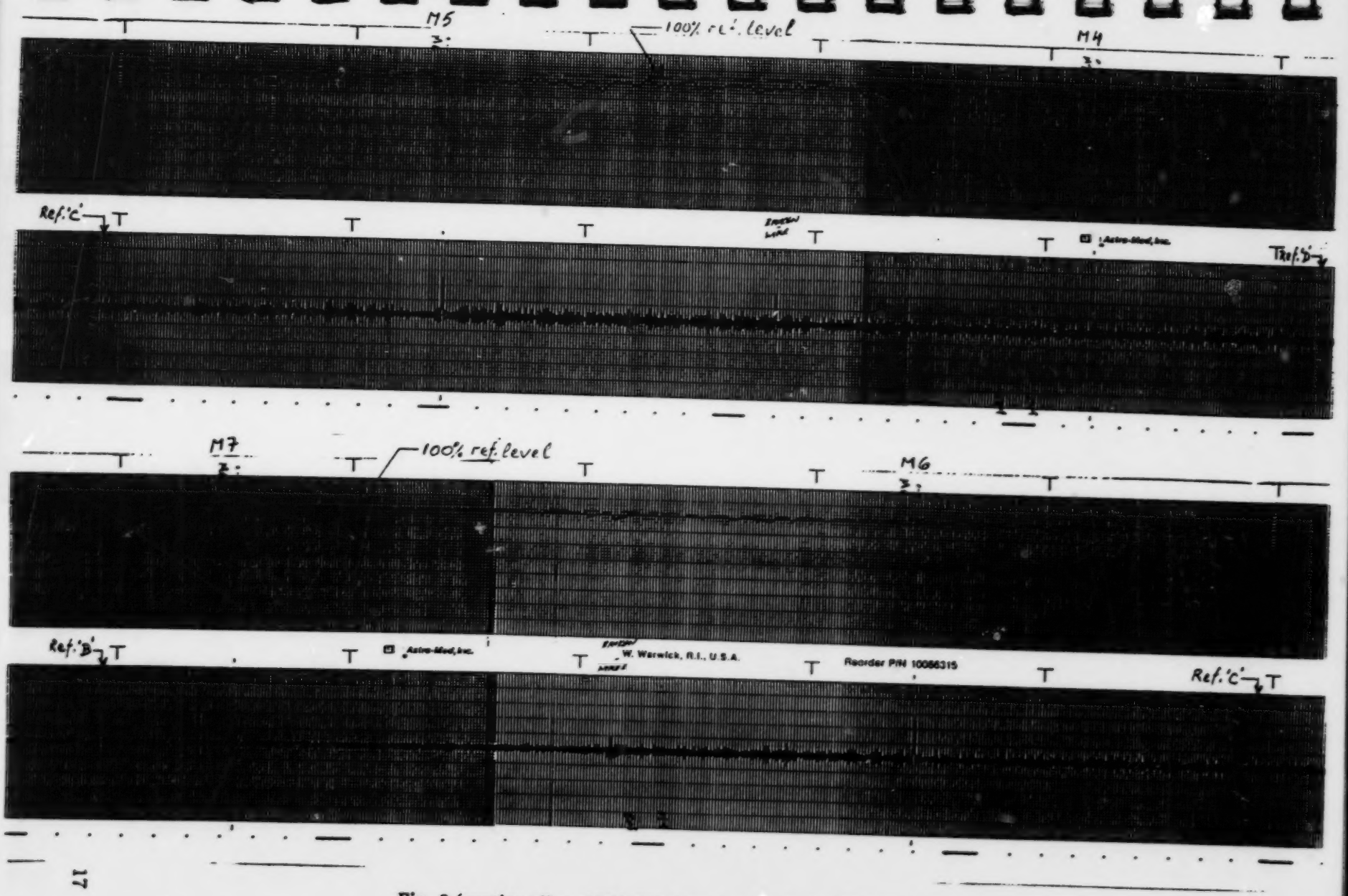


Fig. 3 (continued) — LMA-250 shop-floor test of 1989 04 04

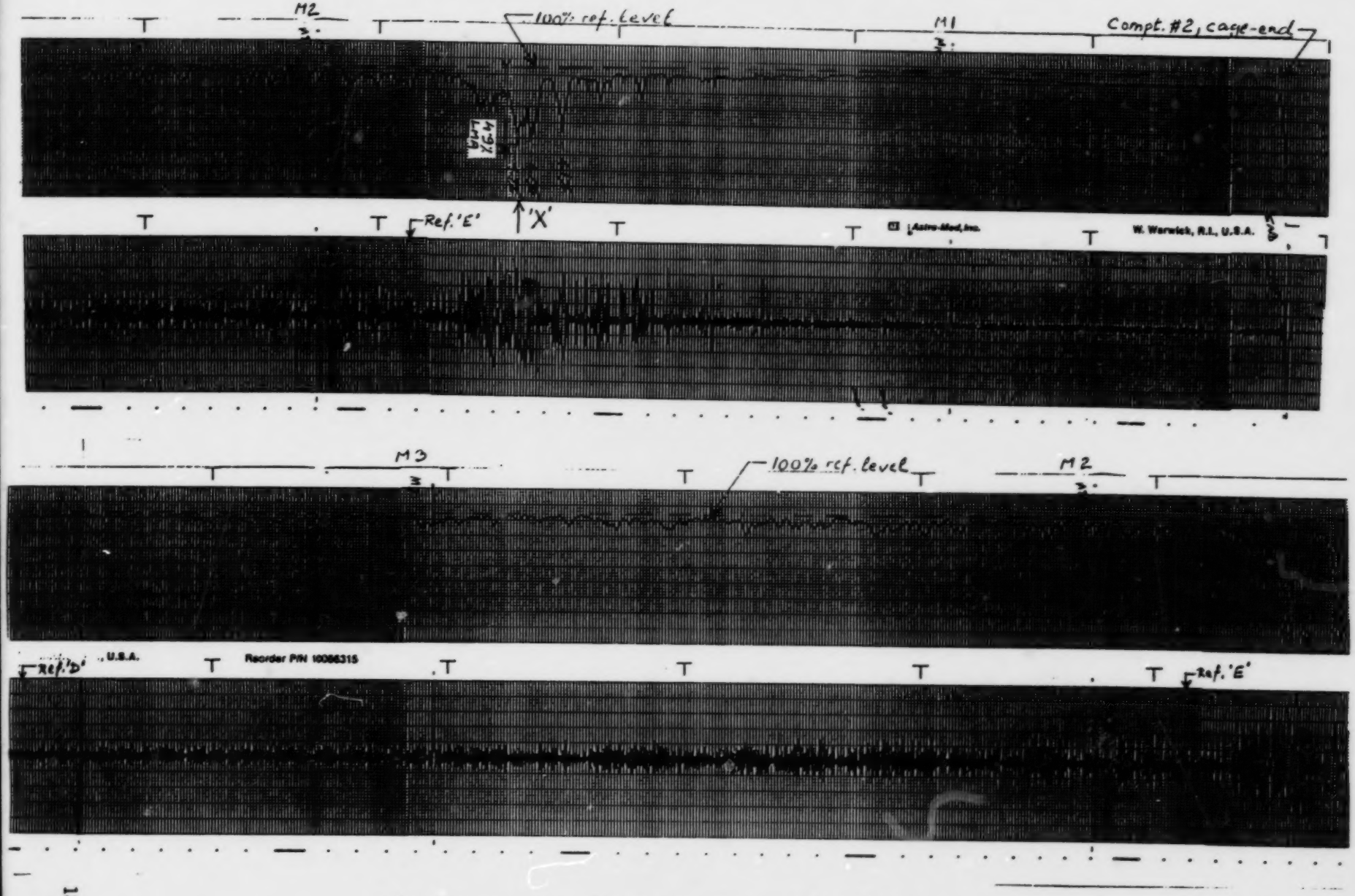


Fig. 3 (continued) — LMA-250 shop-floor test of 1989 04 04

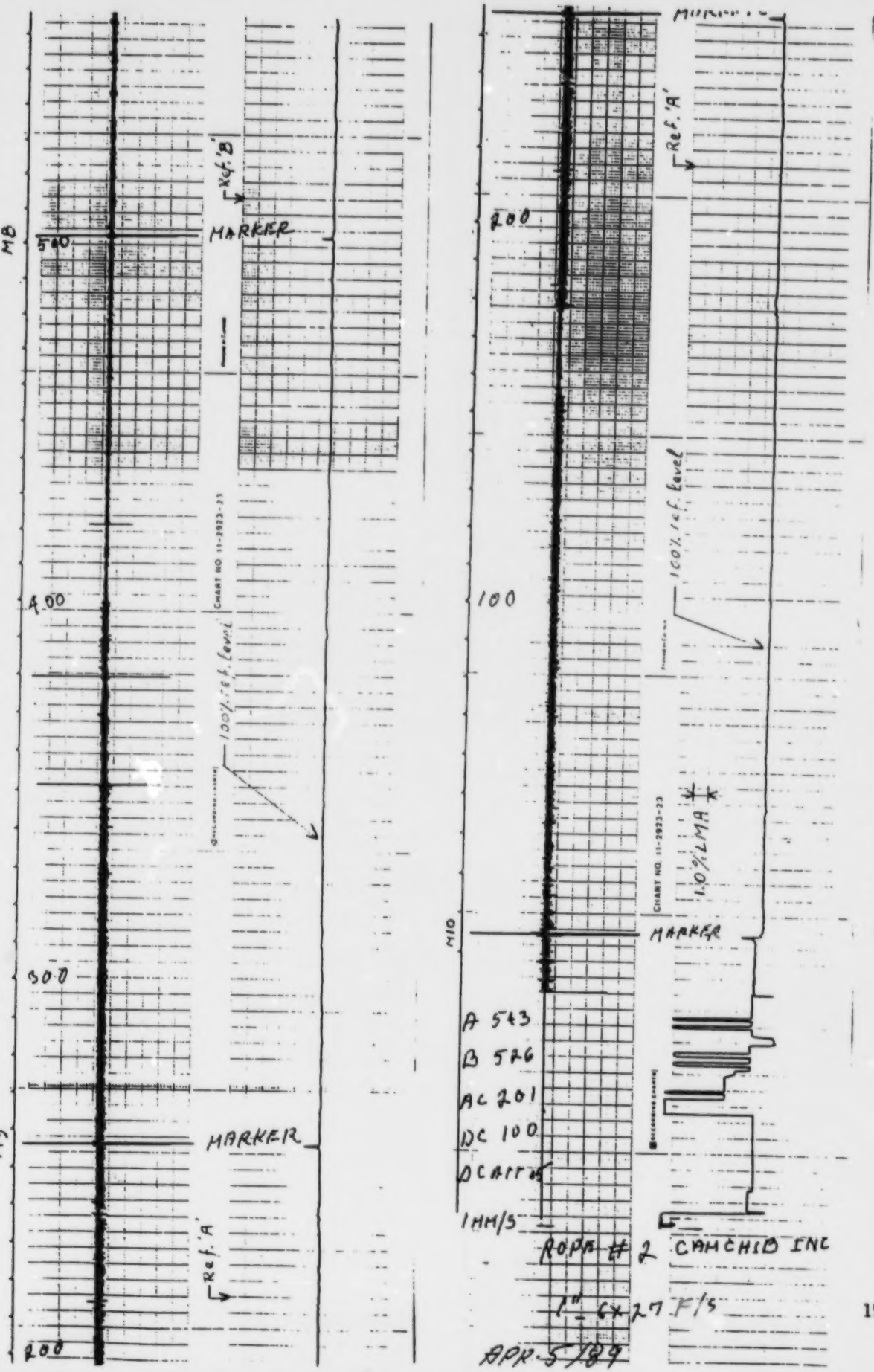


Fig. 4a — Rotescograph shop-floor test of 1989 04 04

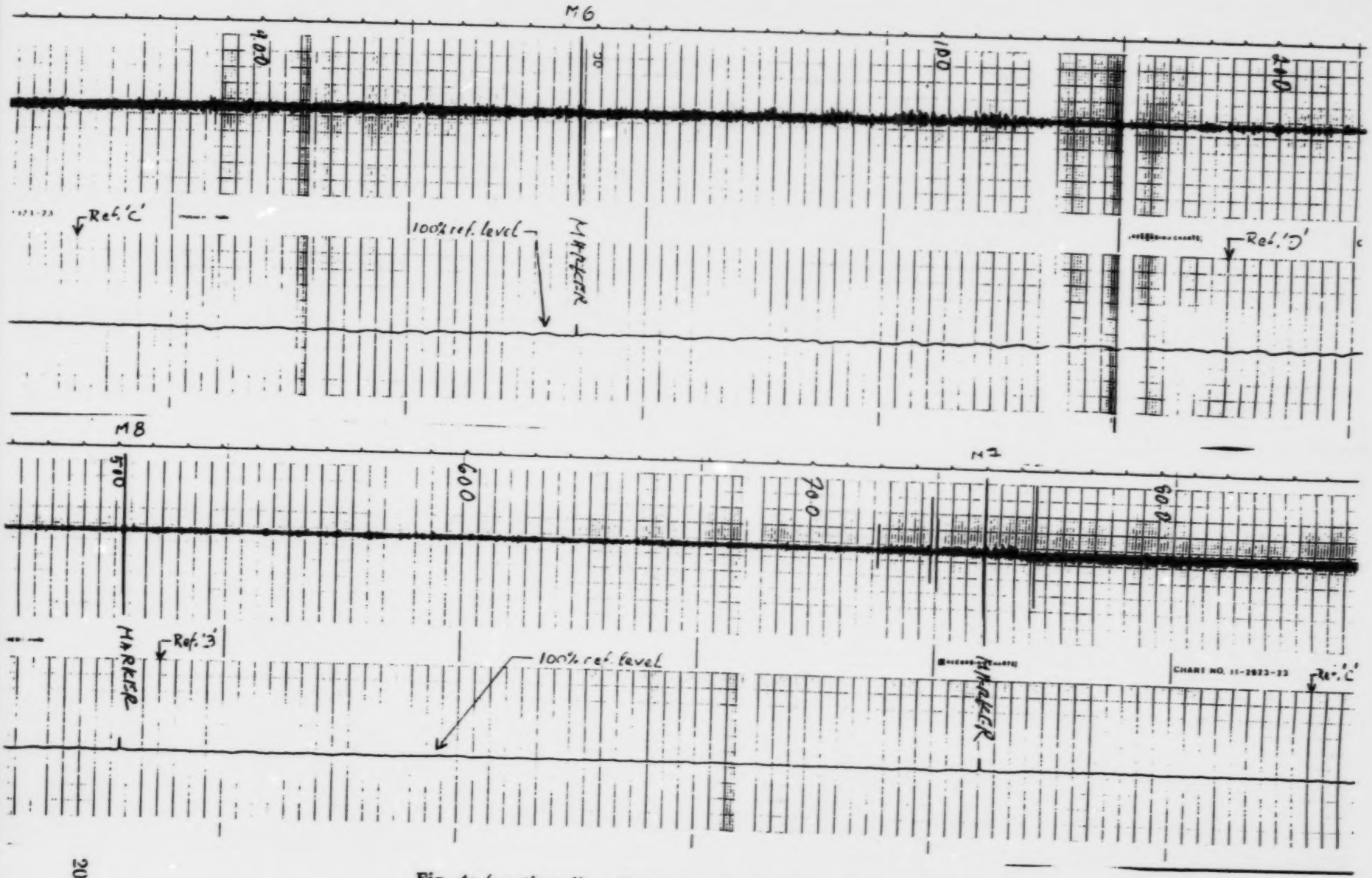


Fig. 4a (continued) — Rotescograph shop-floor test of 1989 04 04

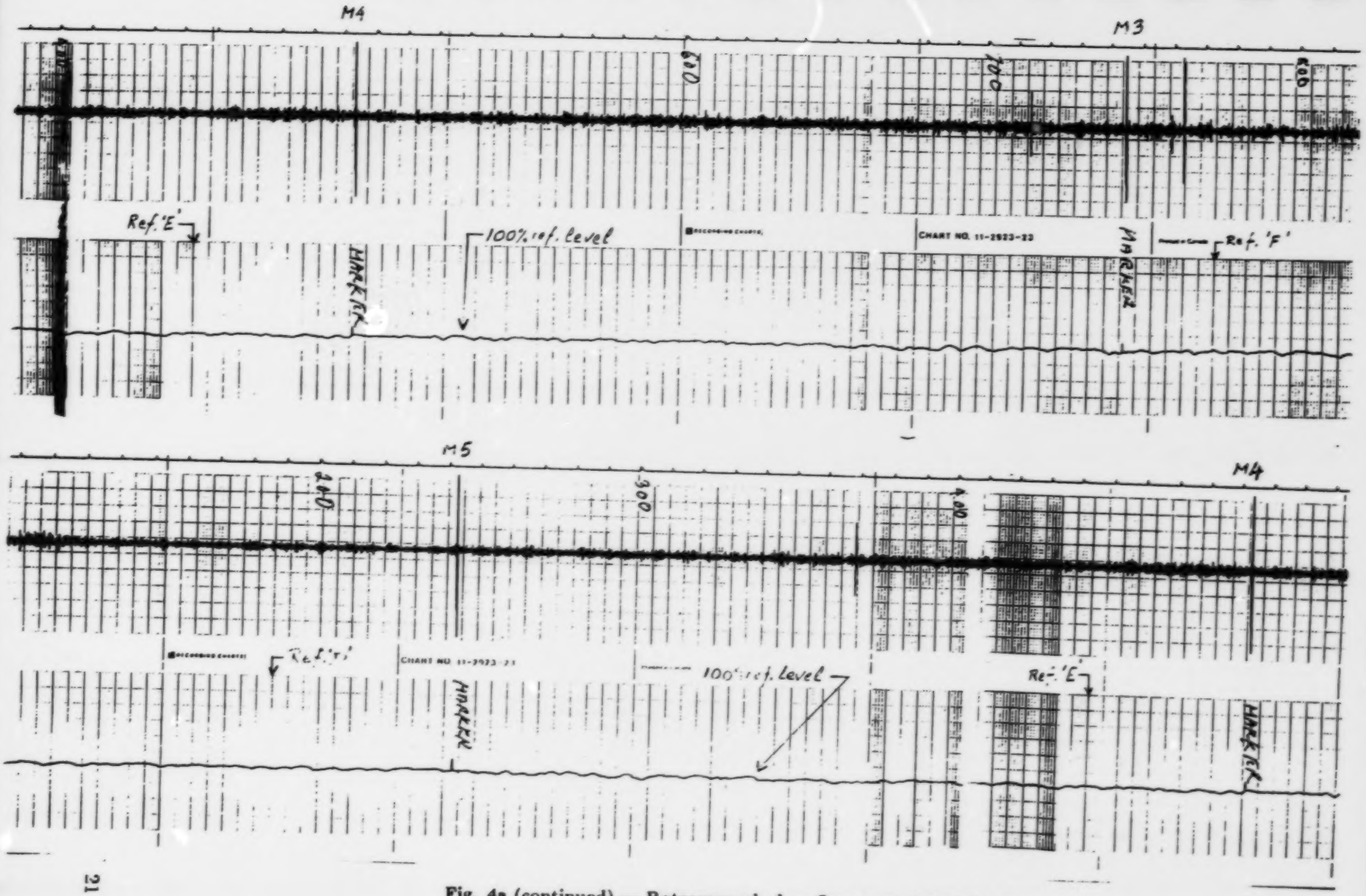


Fig. 4a (continued) — Rotescograph shop-floor test of 1989 04 04

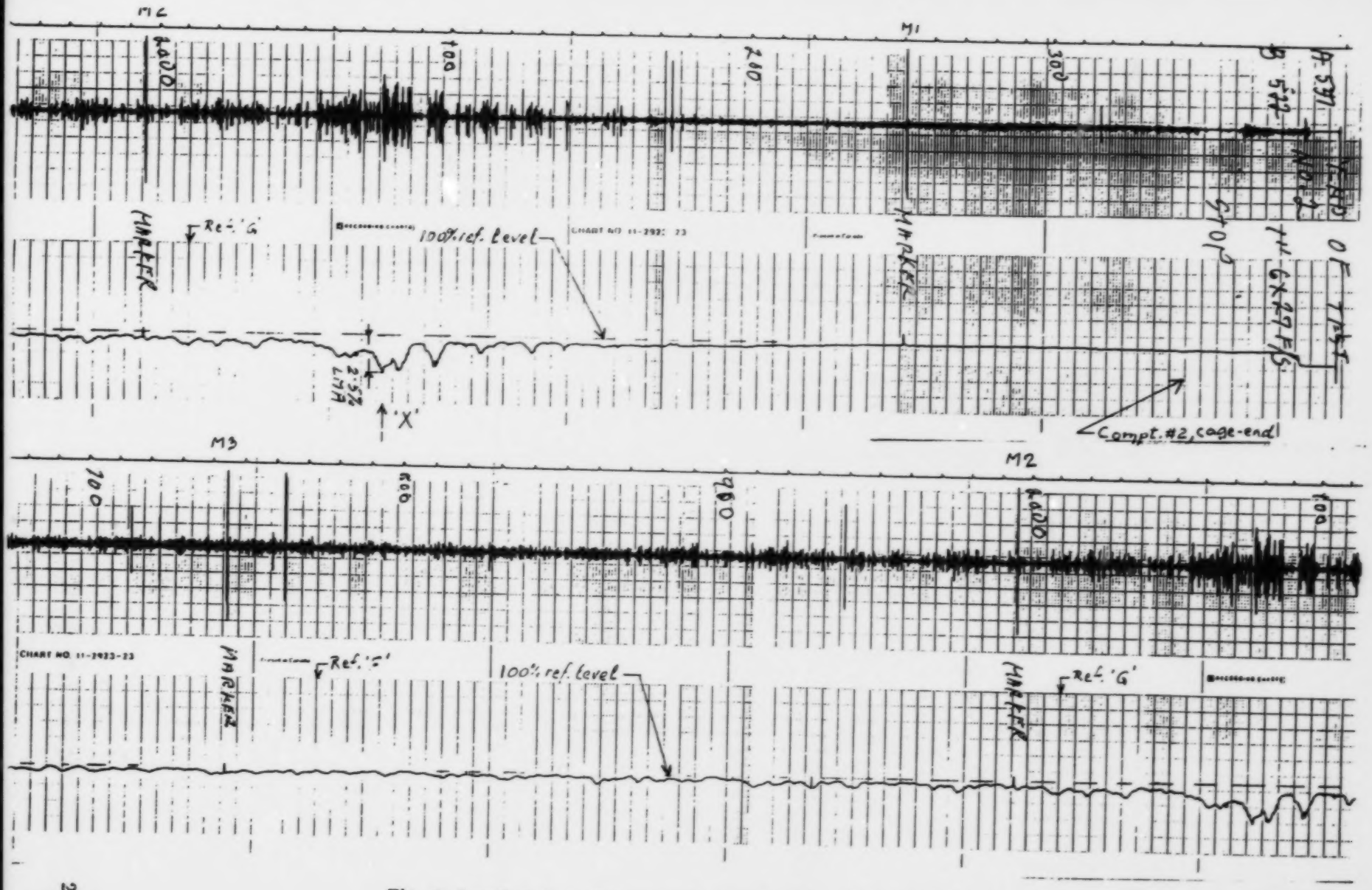


Fig. 4a (continued) — Rotescograph shop-floor test of 1989 04 04

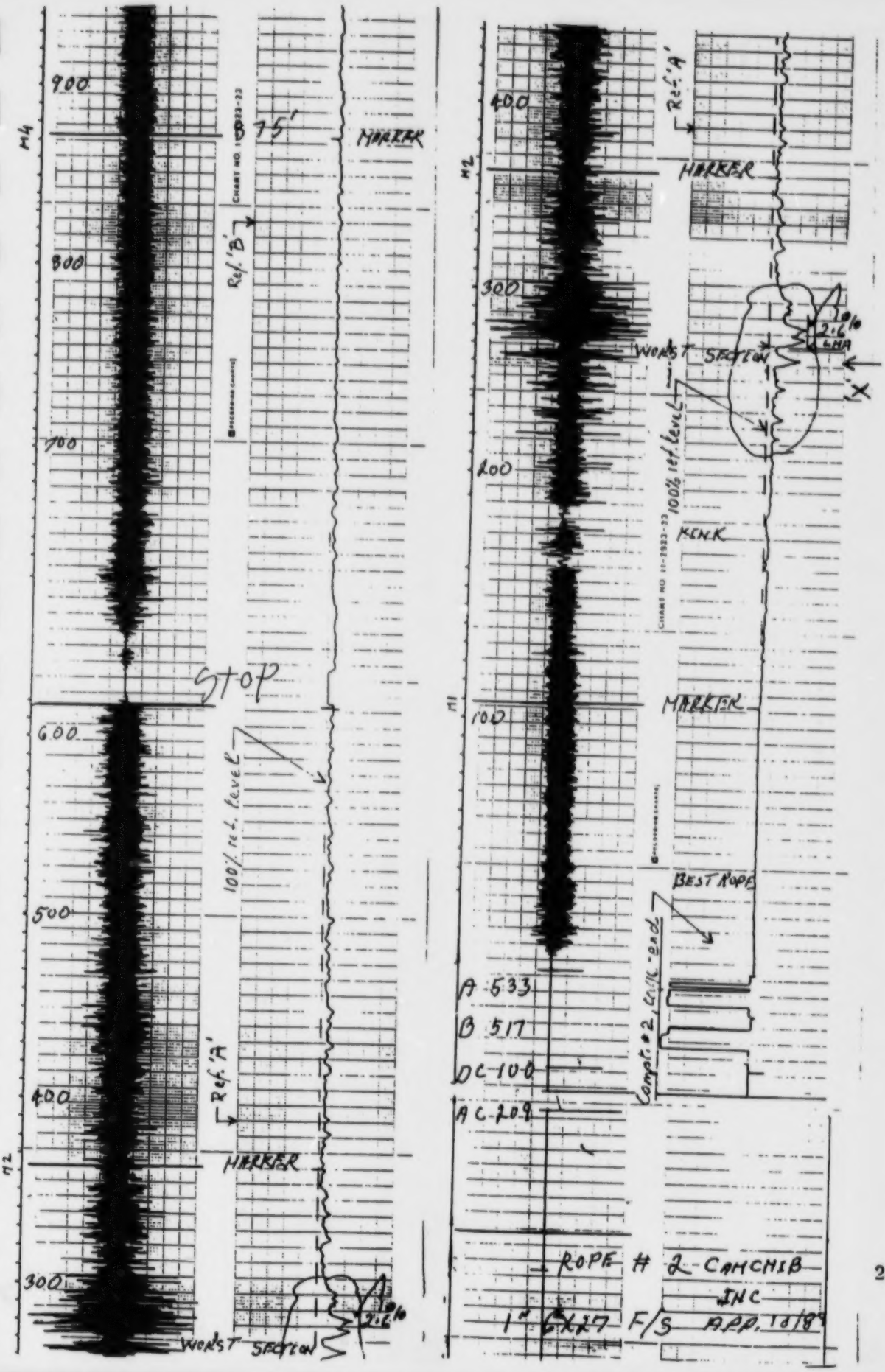


Fig. 4b — Rotescograph shop-floor test of 1989 04 10

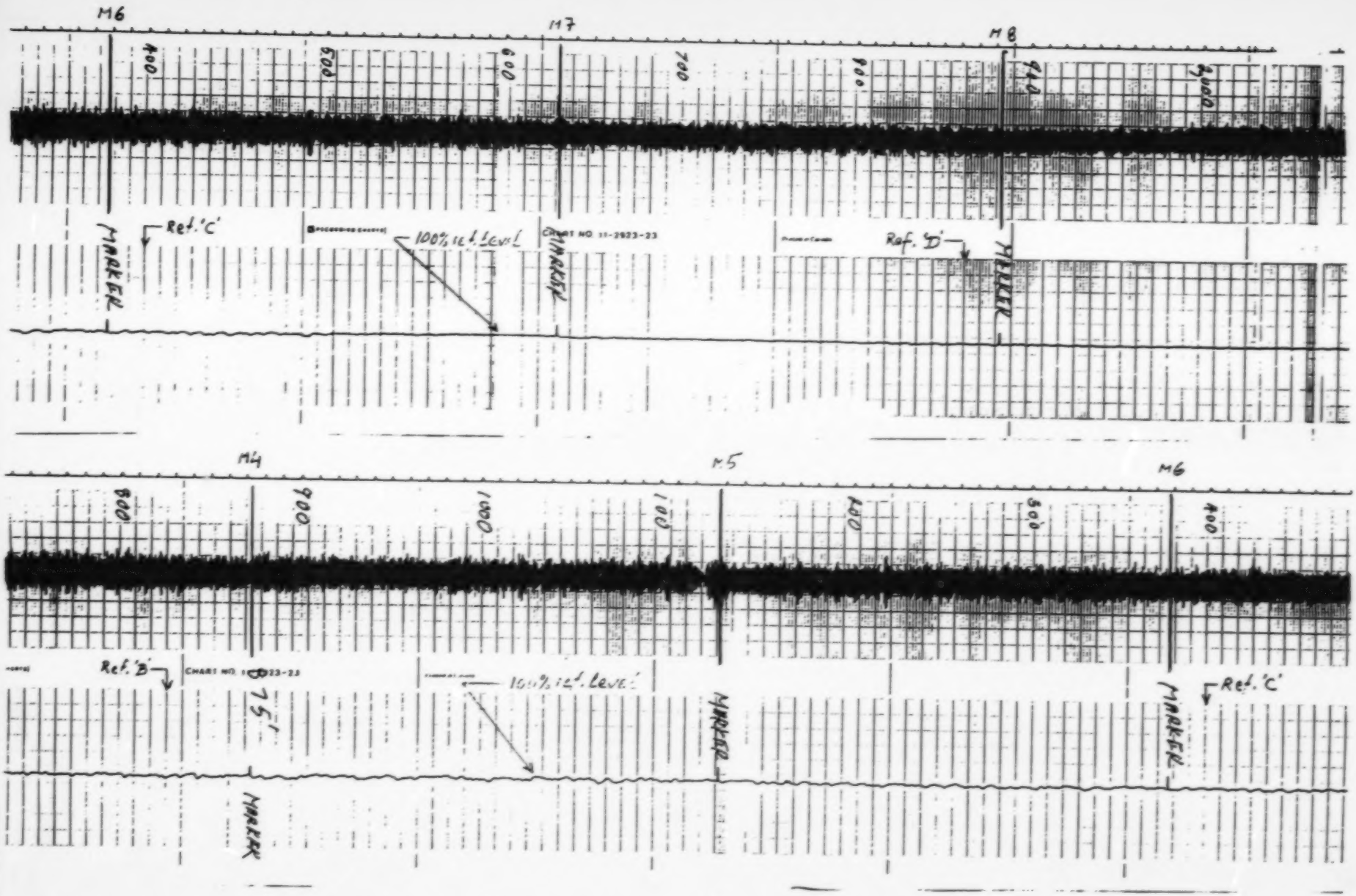


Fig. 4b (continued) — Rotescograph shop-floor test of 1989 04 10

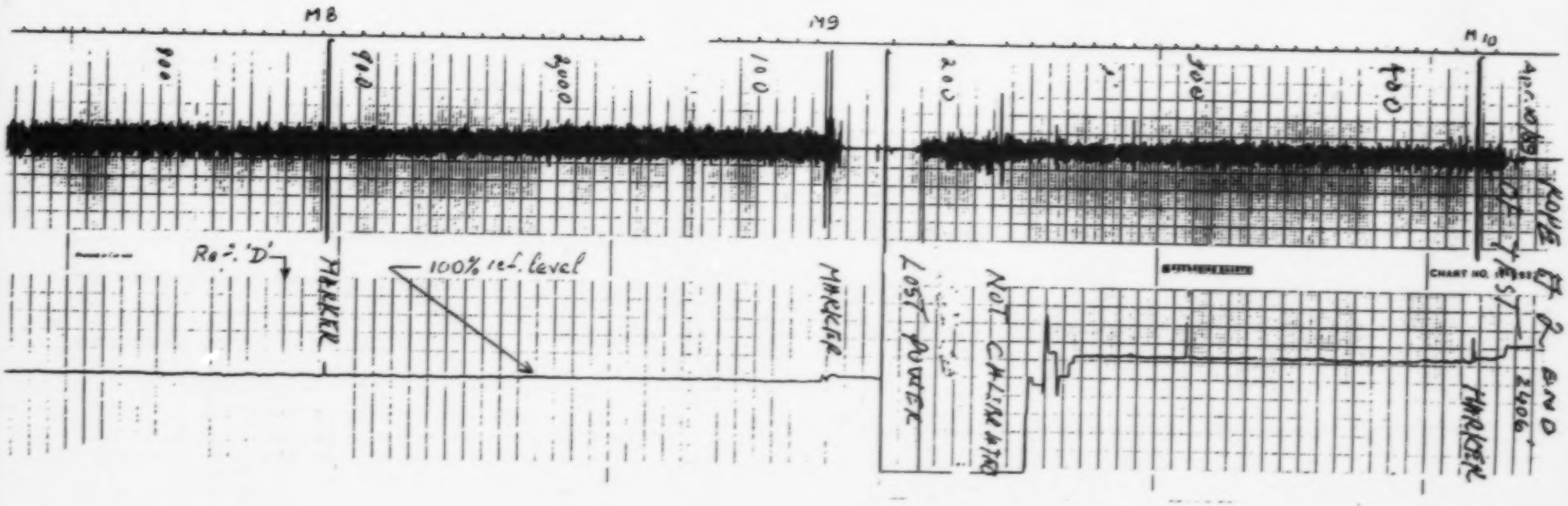


Fig. 4b (continued) — Rotescograph shop-floor test of 1989 (1 10

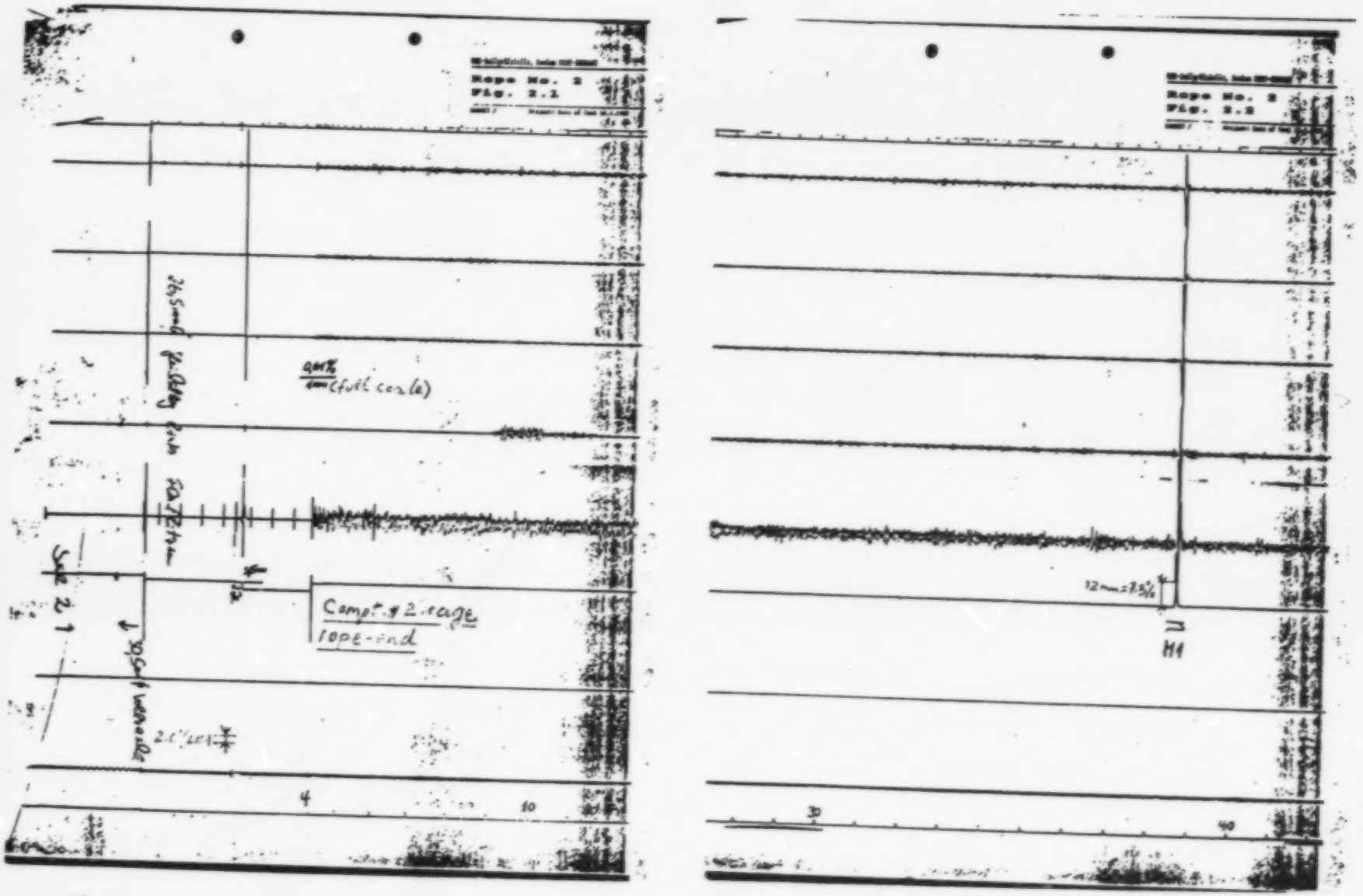


Fig. 5 — WBK shop-floor test of 1989 04 10

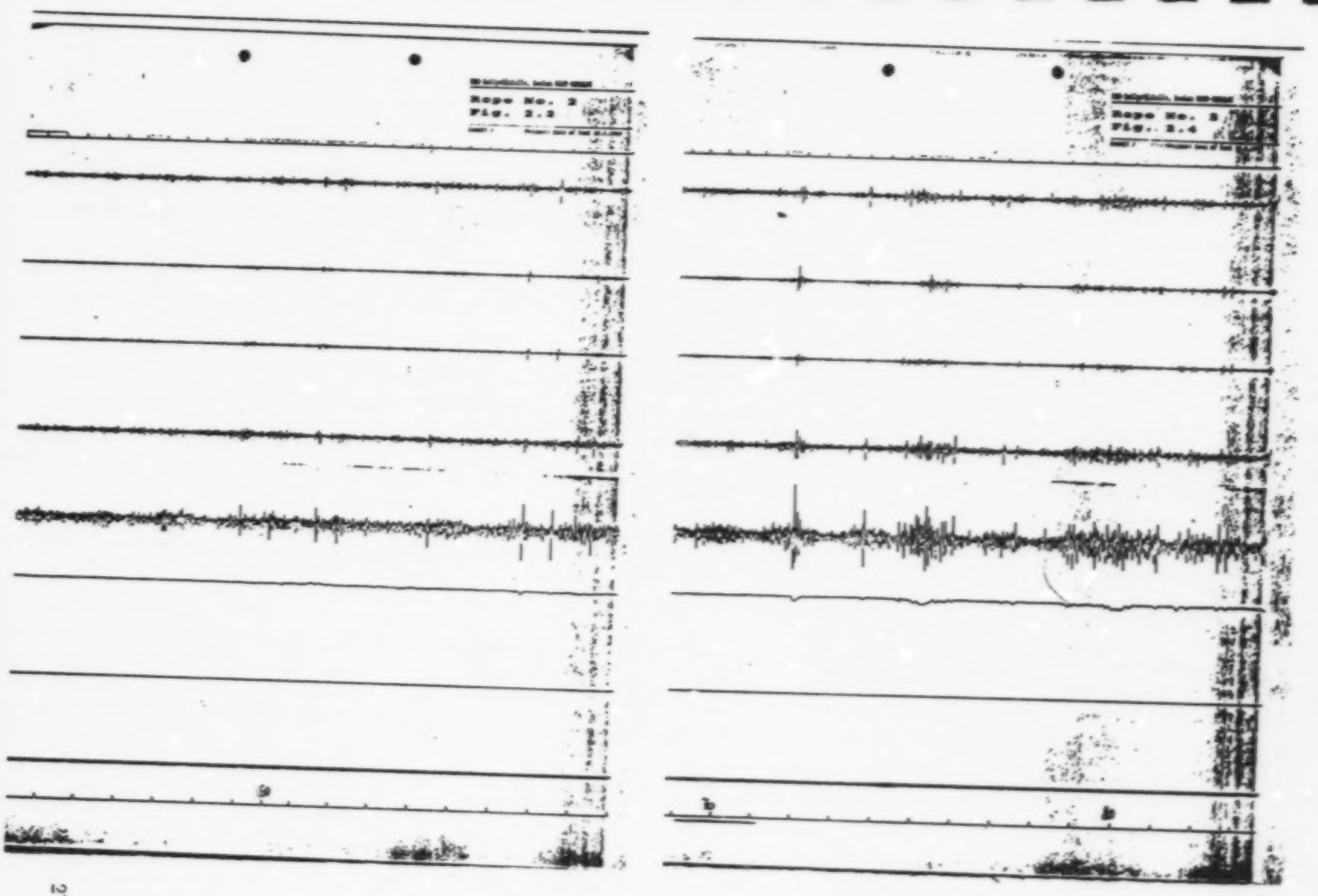


Fig. 5 (continued) — WBK shop-floor test of 1989 04 10

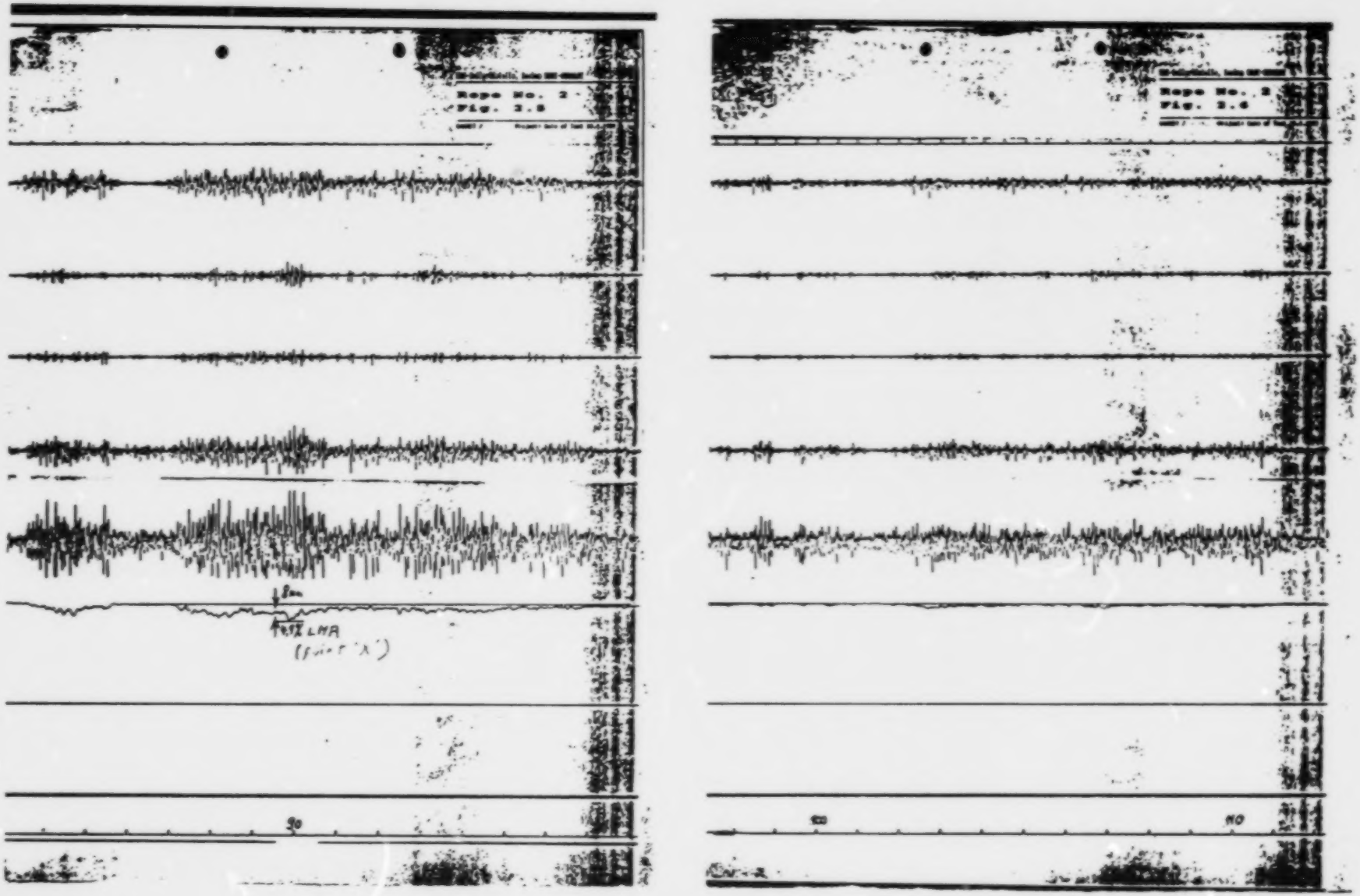


Fig. 5 (continued) — WBK shop-floor test of 1989 04 10

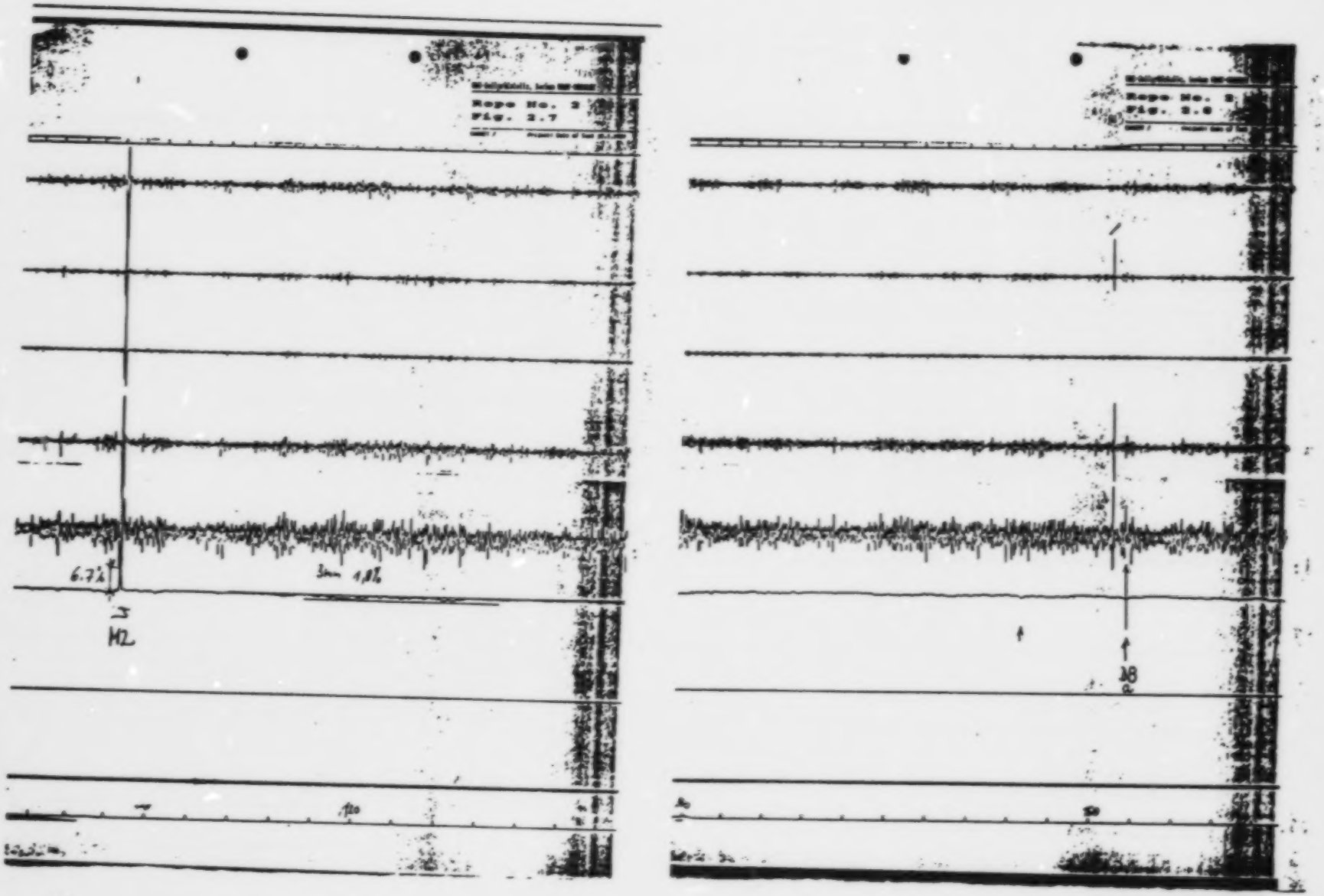


Fig. 5 (continued) — WBK shop-floor test of 1989 04 10

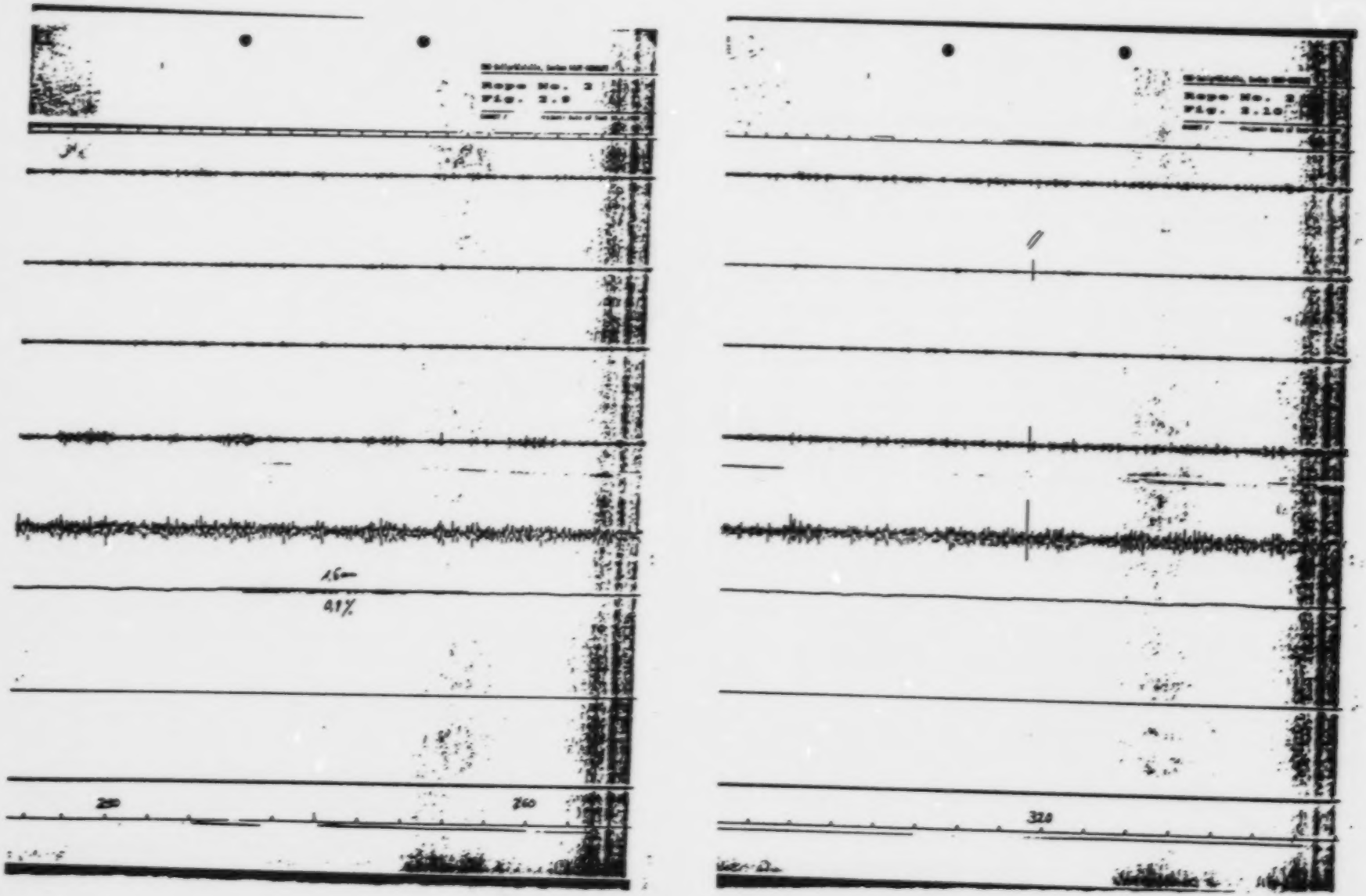


Fig. 5 (continued) — WBK shop-floor test of 1989 04 10

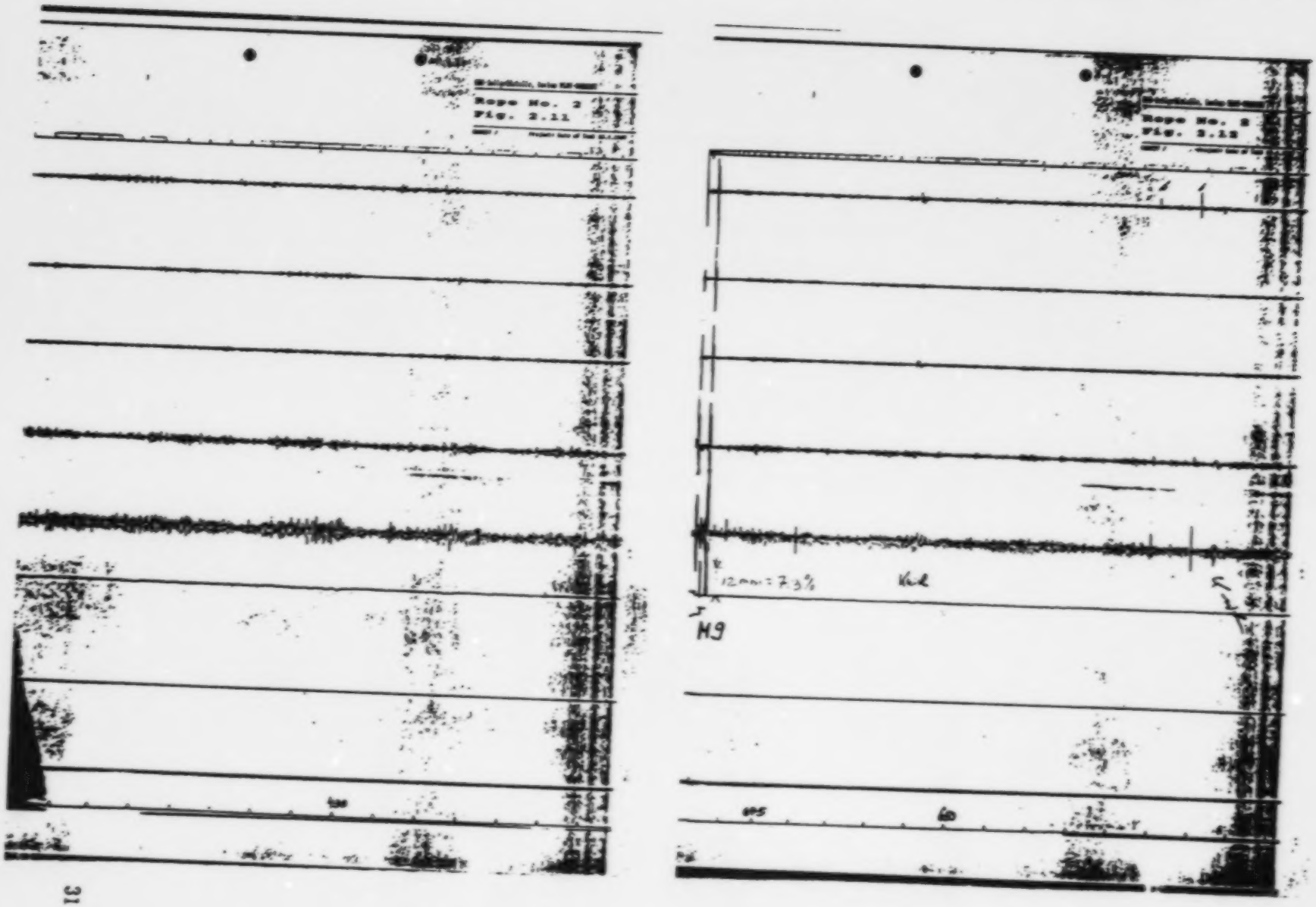


Fig. 5 (continued) — WBK shop-floor test of 1989 04 10

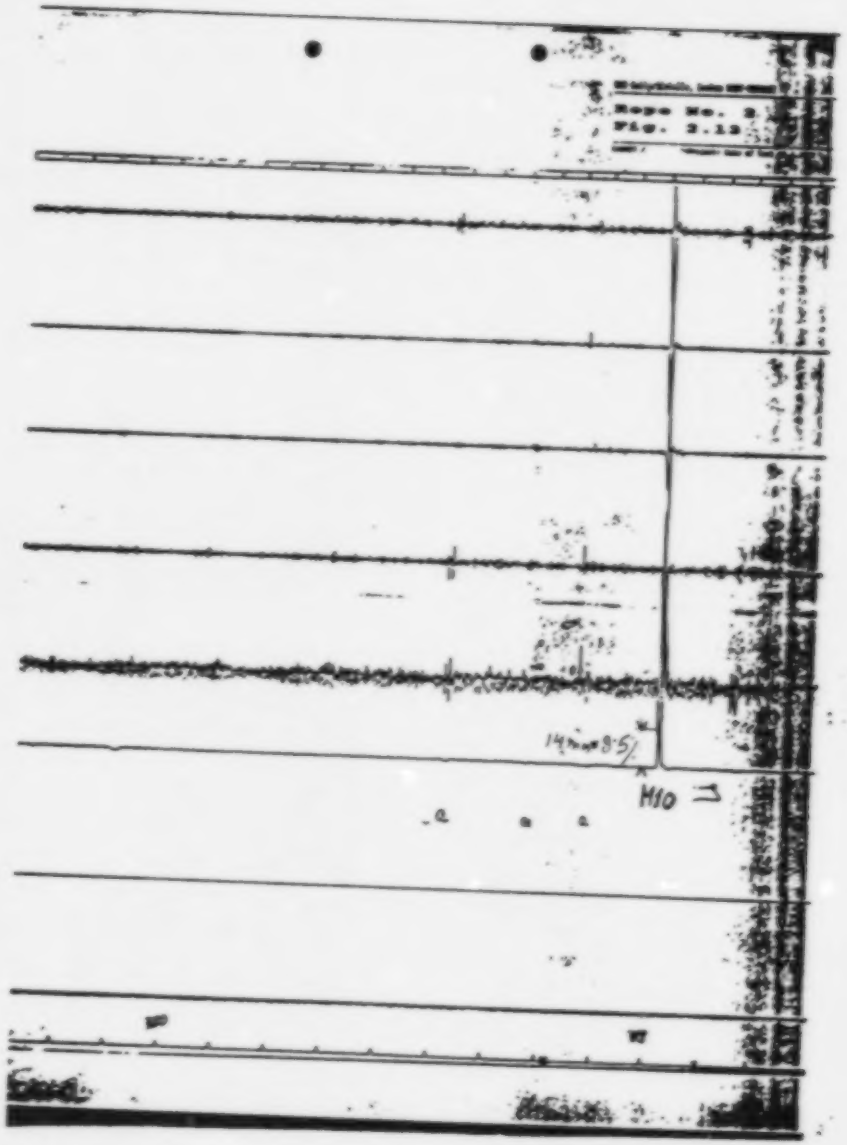
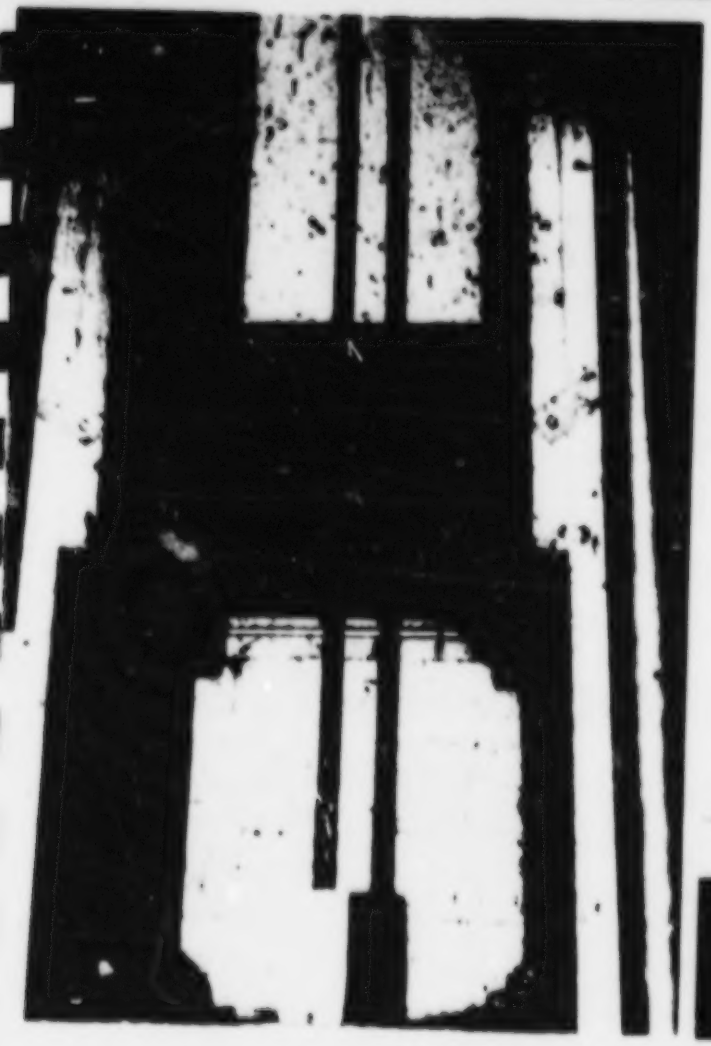


Fig. 5 (continued) — WBK shop-floor test of 1989 04 10



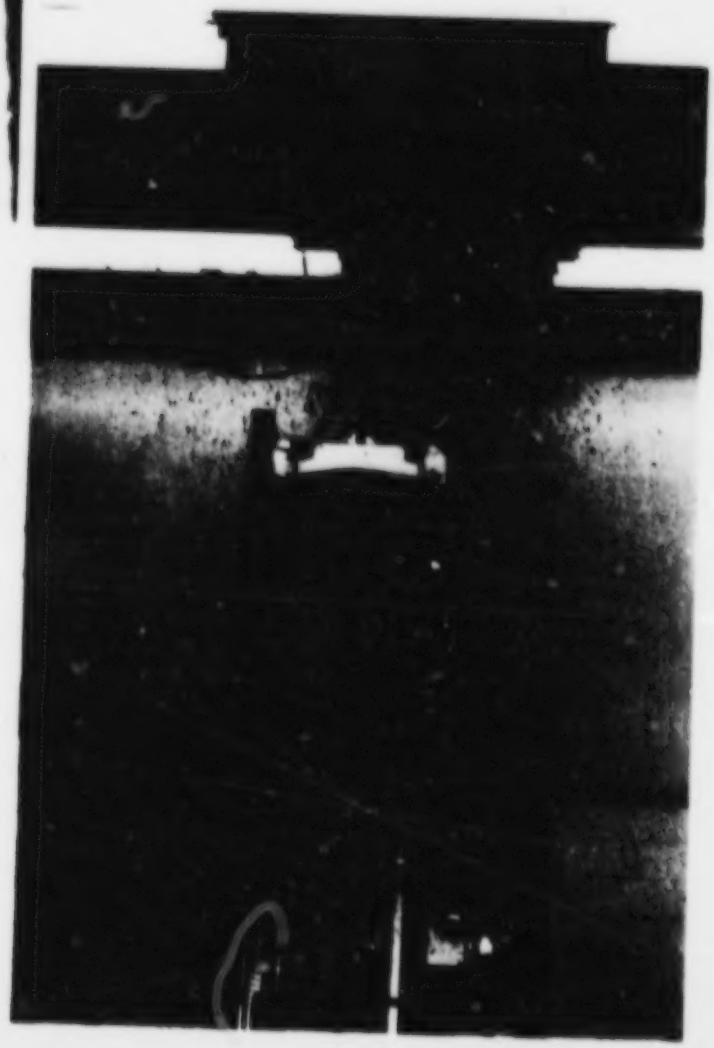


Fig. 6 — Destructive testing:

two views of the general test set-up

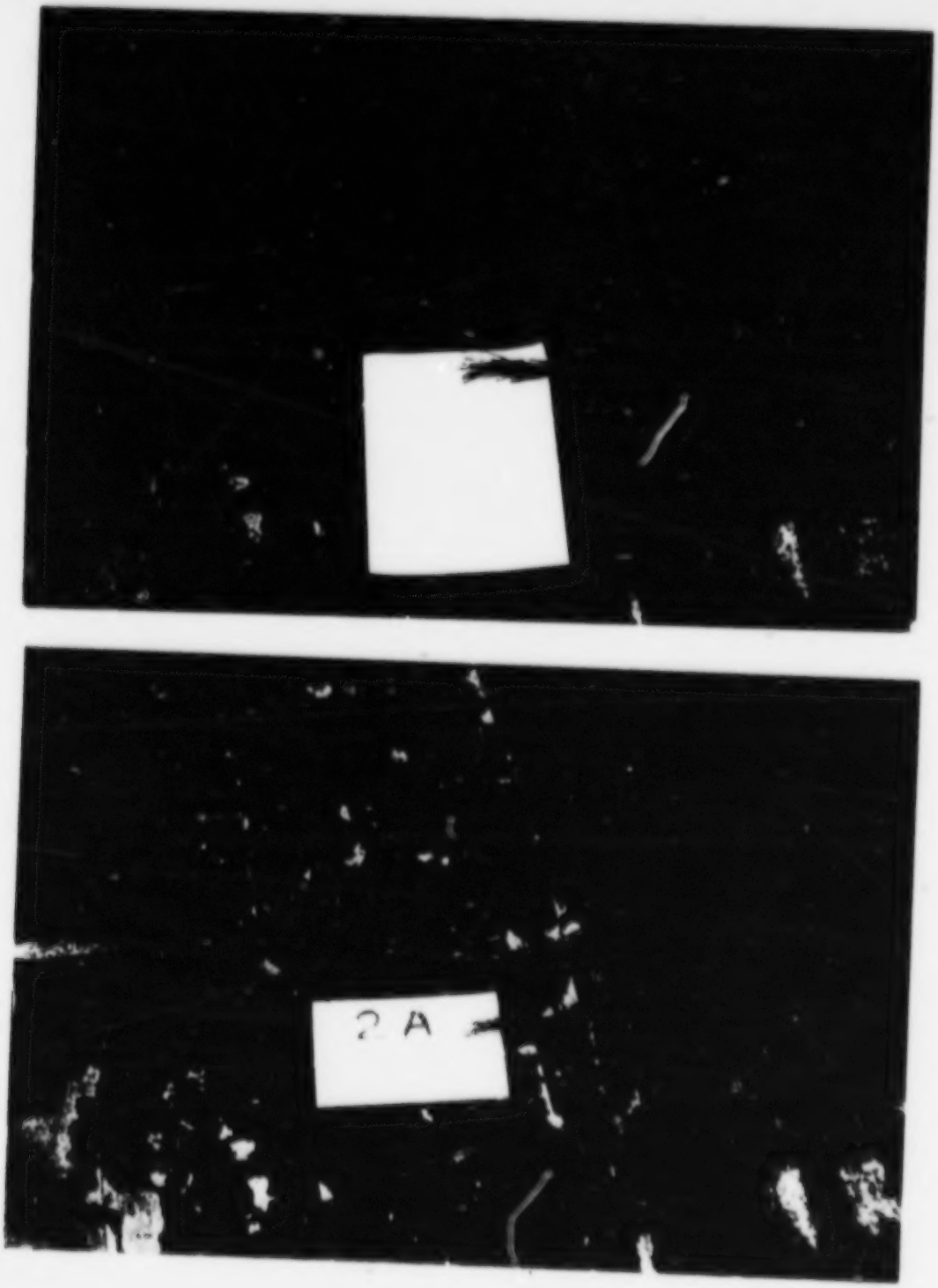


Fig. 7 Two views of broken sample #2a

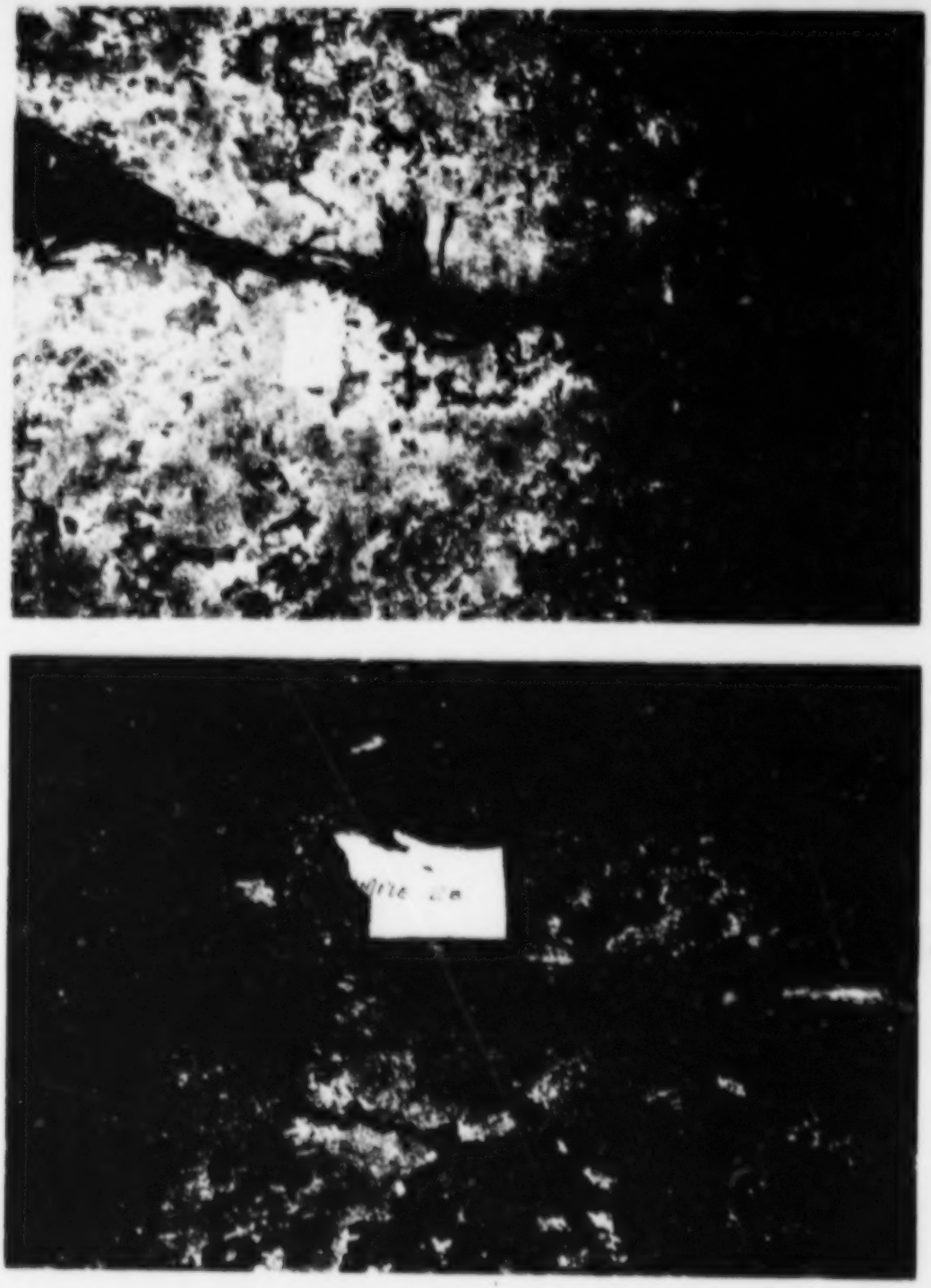


Fig. 8 — Two views of broken sample #2b